Chapter VIII.—THE DURABILITY OF BUILDING STONES IN NEW YORK CITY AND VICINITY. (a)

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The ravages upon our building stones, by that complex association of forces which we call "the weather", are dangerous and rapid. The indications of interest in regard to the serious results, which are sure to come within a short period, are feeble and evanescent. A brief discussion of the main facts and of the principles involved may aid in forming a basis upon which future investigations may rest. The commissioners, appointed by the Department of the Interior "to test the several specimens of marble offered for the extension of the United States Capitol", said in their report of December 21, 1851:

> Though the art of building has been practiced from the earliest times, and constant demands have been made in every age for the means of determining the best materials, yet the process of ascertaining the strength and durability of stone appears to have received but little definite scientific attention, and the commission, who have never before made this subject a special object of study, have been surprised with unforeseen difficulties at every step of their progress, and have come to the conclusion that the processes usually employed for solving these questions are still in a very unsatisfactory state.

Over thirty years have passed since these words were written, and the same methods are still largely in use, although new instruments and processes and rich discoveries concerning the structure of stone have been made available within a quarter of a century. The facts presented have been gathered from many sources published and unpublished, and from long personal observation. It is but a question of time when careful and thorough investigation for the purpose of determining the best means to avert the coming destruction will be called for. It is necessary first to understand the number and the character of the natural foes which are making this deadly attack.

All varieties of soft, porous, and untested stones are being hurried into the masonry of the buildings of New York city and its vicinity. On many of them the ravages of the weather and the need of the repairer are apparent within five years after their erection, and a resistance to much decay for twenty or thirty years is usually considered wonderful and perfectly satisfactory.

Notwithstanding the general injury to the appearance of the rotten stone, and the enormous losses annually involved in the extensive repairs, painting, or demolition, little concern is yet manifested by either architects, builders, or house-owners. Hardly any department of technical science is so much neglected as that which embraces the study of the nature of stone, and all the varied resources of lithology in chemical, microscopical, and physical methods of investigation, wonderfully developed within the last quarter-century, have never yet been properly applied to the selection and protection of stone as used for building purposes.

The various suburbs and vacant districts have been gradually approaching a character sufficiently settled to justify the erection of entire and numerous blocks of private residences, huge buildings for business offices in the lower part of the city and for family flats in the central and upper wards, besides large numbers of public edifices, storage houses, manufactories, etc. The failure of stone to resist fire in the business district, and the offensive results of discoloration or serious exfoliation, which the poor durability of many varieties of stone has rendered manifest in all parts of the city, have already largely diminished its proportionate use, in reference to brick. Nevertheless great quantities of stone of many kinds are yet introduced, as ashlar or the trimmings of apertures, into the buildings now in progress, and will soon be further employed, if the present activity in building be continued, not only in the private enterprises already mentioned, but in others of more lasting and public importance; *e. g.*, the projected improvements and additions in connection with our water supply, as aqueducts and reservoirs; the new bridges proposed over our rivers; the replacement of our rotting wooden docks by more permanent structures; and perhaps, we may hope, the huge pedestal to support the statue of Liberty on an island in our harbor. As the kinds of building stone brought to this market for these purposes are increasing in number and variety, and their selection and mode of use, as it seems to me, are irregular and indiscriminate, whether from the ignorance or the carelessness likely to prevail in a busy, money-getting community, it would appear proper that a voice of warning should now be heard, calling attention to the dangers involved in the use of bad stone or the bad use of good stone; in the enormous waste and expense soon required for repairs in our severe climate, or in the consequent disuse of stone in favor of brick, by a natural reaction, to the injury of the beauty and comfort of our city.

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a From the commercial relations of New York to the quarries of this country and of foreign countries, and from the enormous scale on which the practical value of building materials is tested in that city, this chapter, though local in title, forms the best available summary upon the durability of building stone for the United States, and is therefore placed in the present order.

There are three classes in the community to which such a warning is addressed:

1. A considerable number of house-owners, to whom it seems to come too late, since they have already expended tens of thousands of dollars in temporary repairs, patching and painting decayed stone, and many of whom have doubtless made rash vows to use hereafter, in construction, brick, iron, terra-cotta, wood—anything but stone.

2. House-owners, not yet aware of the coming dilapidation, and who can yet take precautions to delay or prevent its arrival—or others about to build, and who have implicit faith in the eternity of building-stone, since it comes from the "everlasting rock", or at least in a duration which will last their lifetimes—and also a certain proportion of builders and architects willing to learn, and who have much to learn, since the practical scientific study of building stones is yet to be made.

3. And lastly, the architects, builders, and contractors, who know all about the subject, or who do not care what happens to the houses they build, and that large part of our population who never expect to own any houses. To all these the decay of the stone in this city is a matter of indifference, and the quotation presented below—"scarcely a public building of recent date will be in existence a thousand years hence"—few of them, indeed, over a century or two, in fair condition—is only a matter of jest.

1.—EFFECTS OF WEATHERING UPON THE BUILDING STONE OF NEW YORK, ETC.

In foreign countries the subject of the attack of atmospheric agencies on building stones has received much attention, particularly within the last half century, and much earnest effort, though as yet ill-systematized and ill-regulated, has been exerted for their protection by means of the new light and facilities of modern sciences. The contrast between the durability of the stone buildings erected in modern and in the most ancient times is strongly marked:

In modern Europe, and particularly in Great Britain, there is scarcely a public building, of recent date, which will be in existence a thousand years hence. Many of the most splendid works of modern architecture are hastening to decay in what may be justly called the infancy of their existence, if compared with the dates of public buildings that remain in Italy, in Greece, in Egypt, and the East.—*Gwilt's Encyclopedia of Architecture.*

In England this is largely due to the general use of soft freestones, both sandstones and, especially in London, earthy, loosely compacted limestones. Before the erection of the houses of parliament a royal board of commissioners was appointed for the selection of the proper building stones, and a large amount of information was collected on the subject of the modes and rapidity of weathering of the various building stones throughout the United Kingdom. So difficult and novel, however, was the investigation that the results obtained have been only partially successful, both in the selection of the stone, and, on its incipient attack by the atmosphere of London, in the artificial means suggested for its preservation. Only last year the statement was made, in reference to the building of the royal courts of justice, just erected and inaugurated in London:

What will be the fate of its exterior carvings and frettings after another fifty years of London smoke, all of us can tell. The same may be said of a thousand other buildings, great and small, that the past generation of Londoners has raised as monuments of its own ignorance of the simplest conditions of good building. They carve their fronts with carvings of flowers and fruit, which in a year the soot will blacken past recovery, and in five years corrode beyond recall.

We see important and costly edifices restored in the lifetime of the architects who designed them, and palaces patched with cement and painted over every three or four years, before their builders have passed away. * * * No remedy has been found for the decay of soft calcareous stone in our smoky cities; and yet, in our childish helplessness, we continue to use it daily and year after year, as if we had no warnings of the folly of doing so. (*a*)

In a recent investigation of the subject, founded largely on a study of the stone monuments in the grave-yards of Edinburgh, Dr. A. Geikie, of the geological survey of Great Britain, has pointed out that in a town the weathering action differs from that which is normal in nature; on the one hand in the formation of sulphuric acid from smoke, causing more rapid decay of stone-work; on the other in the inferior range of temperature in towns and less severe action of frost.

Dr. Geikie also found that sandstones, if siliceous, were sometimes only roughened in two hundred years. When colored the destruction goes on by solution of cement, or of the matrix in which the particles of silica are embedded, *e. g.*, clay, carbonate of lime, and iron and hydrous and anhydrous ferric oxide. In this material he estimated the rate of lowering to amount to three-quarters of an inch in a century.

In the stone of the buildings of New York and adjacent cities the process of disintegration and destruction is widespread, and yearly becoming more prominent and offensive.

GNEISS.—The commissioners of the Croton Aqueduct department, in their annual report for 1862, page 67, make the following statement:

The retaining-walls of the embankments in many cases require extensive rebuilding. Most of these walls have been constructed of the stone found in their immediate neighborhood—often of a very inferior and perishable character. Thus far we have been able to keep these walls in comparatively good order by removing every year portions of disintegrated stone and replacing them with durable material; but during the past year such large portions, and at so many points, are giving way in mass, that an increased amount must necessarily be expended on them during the coming season.

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a The Builder, 1881, p. 708.

MARBLE.—Italian marble has been found incompetent to withstand the severity of our climate, when used for outdoor work; and of this good illustrations are shown in the pillars, once elegantly polished, in the portico of the church on the southeast corner of Fourth avenue and Twentieth street, etc. The same objection has been urged to the outdoor use of American marbles in our cities, supported at least by their rapid discoloration, but the question is yet unsettled.

Professor Hull observes:

From the manner in which the buildings and monuments of Italy, formed of calcareous materials, have retained to a wonderful degree the sharpness of their original sculpturing, unless disfigured by the hand of man, it is clear that a dry and smokeless atmosphere is the essential element of durability. In this respect, therefore, the humid sky and gaseous air of British towns must always place the buildings of this country at a comparative disadvantage as regards durability.

And again:

Under a smokeless atmosphere it is capable of resisting decay for lengthened periods, though it becomes discolored. * * * The perishable nature of the marble when exposed to the smoky atmosphere of a British city, is evinced by the decayed state of the tomb of Chantrey, erected in 1820, in the "God's acre" belonging to St. John's Wood chapel.

Another example of this decay is shown in the group of Queen Anne, etc., erected from Carrara marble, about the beginning of the eighteenth century, before the west front of St. Paul's, in London, England, and which has been covered throughout with a coat of paint in the hope of slightly retarding its inevitable decay. The dolomitic marble of Westchester county has been largely employed in our buildings, and some idea of its character for durability may now be gained. A fine-grained variety was used in the building of the United States assay-office, in Wall street; its surface is now much discolored, and the edges of many of the blocks show cracks. A variety of medium texture was employed in the hotel at the corner of Fulton and Pearl streets, erected in 1823; the surface is decomposed, after the exposure of exactly sixty years, with a gray exterior, in a crust from one-eighth to one-fourth inch in thickness, soft and orange-colored in section. Many crystals have fallen out of the surface on the weathered eastern face, producing a pitted appearance. A very coarse variety has been used in the bank building at Thirty-second street and Broadway, in large part being set on edge; very many of the blocks are more or less cracked, even in the highest story. In the United States Treasury building, in Wall street, a rather coarse dolomite-marble, rich in tremolite and phlogopite, was used, the blocks being laid on bed in the plinth and most of the ashlar, but largely on edge in the pillars, pilasters, etc.; in the latter case vertical fissures commonly mark the decay, but even elsewhere a deep pitting has been produced by the weathering out of the tremolite. The marble used in many other prominent buildings has been improperly laid, *e. g.*, in both of the buildings of the city hall, the Drexel building, at the corner of Broad and Wall streets, the Academy of Design, at Twenty-third street and Fourth avenue, etc. The same process of ultimate ruin in its incipient stages is abundantly shown, even in the marble slabs in Saint Paul's church-yard and monuments of Greenwood cemetery, by discoloration and disintegration of surface. In the United States hotel, on Fulton street, constructed of Westchester marble in 1823, we have the opportunity to study the effect of weathering for over a half century. Though presenting a good appearance at a distance, the stone has become pitted by the falling out of grains, especially on the east side, and is tinged a dirty orange by a crust of decomposition from one-sixteenth to a quarter of an inch in depth.

The horizontal tablets, supported on masonry which has partially settled (*e. g.*, J. G., 1821), generally show a slight curvature in center, only in part, possibly, produced through solution by standing rain-water.

Dolomieu first made the observation on an Italian marble, called betullio, that it possessed a degree of flexibility allied to that of the itacolumite of Brazil. Gwilt states (*Encyclopedia of Architecture*, p. 1274):

Some extremely fine specimens of white marble are to be seen in the Borghese palace at Rome, which, on being suspended by the center on a hard body, bend very considerably. It is found that statuary marble exposed to the sun acquires, in time, this property, thus indicating a less degree of adhesion of its parts than it naturally possessed.

In the white-marble veneering of the façade of St. Mark's, Venice, the same effect has been observed by Mr. C. M. Burns, jr., in the lower half of a slab of veined marble, 2 inches thick, on the south side of the northernmost of the five portals, just behind the columns and about 5 feet from the pavement. The slab is 11 feet 2 inches long, and 1 foot 6 inches wide; it is hung to the backing by copper hooks driven into the brick-work, but the lower part, for a distance of 5 feet 7 inches, bulges out $2\frac{3}{4}$ inches from the backing.

The exposure is directly westward, and I found that it became decidedly warm in the afternoon sun, while the backing would be likely to keep its temperature lower. Though the outer surface is somewhat weatherworn, I could not find the slightest tendency to fracture in any part.—*The American Architect and Building News*, 1882, p. 118.

Also at the palace of the Alhambra, in Grenada, Spain, one of the two doors that have been christened "La Mezquita" exhibits an ancient facing of three slabs of marble, the upper resting as a lintel upon the two others, which form uprights, 11 feet in height, 9 inches in width, and only $2\frac{1}{2}$ inches in thickness. At $18\frac{1}{2}$ inches from the top of the door the slab on the right begins to curve and to detach itself from the wall, attaining the distance of 3 inches at about 3 feet from the bottom. From a subsidence of the material of the wall an enormous thrust has been exerted upon the right, and the marble, instead of breaking or of rupturing its casings, has simply bent and curved as if it were wood.—*La Nature*, 1882.

I have also been informed at Sutherland Falls and other quarries near Rutland, Vermont, that the bending of thin slabs of marble exposed to the sunshine in the open air, and accidentally supported only at the ends, has been there repeatedly observed.

Fleurian de Bellevue discovered a dolomite possessed of the same property in the Val-Levantine, of Mount Saint Gothard. Dolomieu attributed the property to "a state of desiccation which has lessened the adherence of the molecules of the stone", and this was supposed to be confirmed by experiments of De Bellevue, who, on heating inflexible varieties of marble, found that they became flexible.

This change, however, cannot be connected with the remarkably small content of water existing in marbles, but with a peculiarity of their texture, which has been briefly discussed by Archibald Geikie (*Proc. Roy. Soc. Edinb.*, 1880), in an interesting investigation on the decay of the stones used in Scotch cemeteries. He has pointed out that the irregular and closely-contiguous grains of calcite which make up a white marble are united by no cement, and have apparently a very feeble coherence.

It appears to me probable also that their contiguous crystallization has left them in a state of tension, on account of which the least force applied, through pressure from without, or of the unsupported weight of the stone, or from internal expansion by heat or frost, produces a separation of the interstitial planes in minute rifts. Such a condition permits a play of the grains upon each other and considerable motion, as illustrated in the commonly-observed sharp foldings of strata of granular limestones, without fractures or faults. In such cases, also, I have observed that the mutual attrition of the grains has been sometimes sufficient to convert their angular, often rhomboidal, original contours into circular outlines, the interstices between the rounded grains being evidently filled up by much smaller fragments and rubbed-off particles; *e. g.*, in the white marble of the anticlinal axis at Sutherland Falls, Vermont.

These results are confirmed by the appearances, familiar to all lithologists, in the study of thin sections of marble, the latent interstices between the grains of calcite having been often developed by the insinuation of films and veinlets of iron-oxide, manganese-oxide, etc. While a polished slab of marble fresh from the stone-yard may not be particularly sensitive to stains, after it has been erected and used as a mantel-piece over a fire-place, its increased absorption of ink, fruit-juices, etc., becomes strongly marked. On this property are founded the processes, always preceded by heat, for the artificial coloring of marbles.

In the decay of the marble, largely Italian, in the atmosphere of Edinburgh, Geikie has recognized three phases:

1. Loss of polish, superficial solution, and production of a rough, loosely-granular surface. This is effected, Geikie states, by "exposure for not more than a year or two to our prevalent westerly rains". The solution of the surface may sometimes reach the depth of about a quarter of an inch, and the inscriptions may become almost illegible in sixteen years.

In our own dry climate, however, these results do not appear. The polish often survives ten years in our city cemeteries, and even for over half a century, near the ground, in the suburban cemeteries; in one instance, at Flatbush, it has remained intact for over 150 years, on the tombstone of F. and P. Stryker, dated 1730. Inscriptions are decipherable in Saint Paul's church-yard back to the date of 1798, but about one-tenth are illegible or obliterated; the latter effect was never seen in a single instance on the suburban stones, and is evidently due to the acid vapors in the rain-waters of the city.

2. Incrustation of the marble with a begrimed, blackish film, sometimes a millimeter in thickness, consisting of town-dust, cemented by calcium sulphate, and thorough internal disintegration of the stone, sufficient, after a century, to cause it to crumble into powder by very slight pressure.

Neither the crust nor any deep disintegration has been observed in the oldest marble tombstones in the cemeteries of New York; their absence is plainly attributable to the inferior humidity of our atmosphere and the absence of smoke from soft coals.

3. Curvature and fracture, observed in slabs of marble, firmly inserted into a solid frame-work of sandstone. This process consists in the bulging out of the marble, accompanied with a series of fractures, and has been accomplished by expansion due to frost. Tombstones are never constructed in this way in our cemeteries; but the curvature of horizontal slabs, observed in Saint Paul's church-yard, produced by the sagging of the supporting masonry beneath the center of the slab, is simply indicative of the flexibility of the material.

Geikie states:

> The results of my observations among our burial-grounds show that, save in exceptionally sheltered situations, slabs of marble exposed to the weather in such a climate and atmosphere as that of Edinburgh are entirely destroyed in less than a century. Where this destruction takes place by simple comparatively rapid superficial solution and removal of the stone, the rate of lowering of the surface amounts sometimes to about a third of an inch (or, roughly, 9 millimeters) in a century. Where it is effected by internal displacement, a curvature of $2\frac{1}{2}$ inches, with abundant rents, a partial effacement of the inscription, and a reduction of the marble to a pulverulent condition, may be produced in about forty years, and a total disruption and effacement of the stone within one hundred. It is evident that white marble is here utterly unsuited for out-of-door use.

My own conclusion, from observations in New York, is that, in the cemeteries within the city, the polish on vertical slabs is usually destroyed in about ten years; that the inscriptions are only in small part effaced within from thirty to fifty years, and are for the most part perfectly legible on the oldest tombstones, dating 1798; and that, although the reduction of the surface to a loose granular condition may reach the depth of ten millimeters, the actual lowering of the surface seldom exceeds 5 or 6 millimeters, the internal disintegration is never sufficient to affect sensibly the strength of the stone during the periods of exposure which have been noted, and a slight flexure, perhaps to the amount of 12 or 15 millimeters, sometimes affects the center of horizontal slabs, 2 meters in length.

In the cemeteries without the city the polish may often survive near the ground, on the faces of vertical slabs, for over one hundred and fifty years, as the granulation of the surface rarely exceeds a depth of 3 or 4 millimeters; and all the inscriptions remain perfect on the oldest vertical tombstones, suffering partial effacement only on horizontal slabs.

Although these facts show the far greater durability of marble in our dry and pure atmosphere, the frequent obliteration of inscriptions, the general, and often rapid, granulation of the surface, and the occasional fissuring of slabs, show that the decay of marble—in the varieties hitherto long used in New York city—is steady, inevitable, and but a question of time; and with Geikie, I, too, am convinced that, if unprotected, such materials are utterly unsuited for out-of-door use, at least for decorative purposes or cemetery records, within the atmosphere of a city.

SANDSTONE.—In regard to brownstone there seems to be a common if not universal opinion—but, in my own view, too hasty, and by no means established—which is presented in the following quotation:

> The days of brownstone fronts for the better class of houses are probably numbered. A thin veneering of soft stone, hooped on to a brick wall, adds almost nothing to the strength of a building. On the exposure of the brownstone fronts for sixty or eighty years to the severity of our climate, in the opinion of intelligent stone-cutters, the majority of them will be in ruins, and the remainder much dilapidated.

In the widely-quoted opinion of one architect, this stone is of no more use for architectural work in this region than so much gingerbread.

Even the brown sandstone of the city hall, originally of a very superior quality, and the crumbling cornices, lintels, etc., of numberless houses which line some of the other streets of the city, evince the progress of the decay. It makes no very great difference whether the stone is laid parallel or perpendicular to its grain. In the former case its destruction is more rapid; in the latter, rottenness soon appears in the lintels, columns, cornices, and other projecting portions of the edifice. Several of the fronts along Fifth avenue, some of them less than ten years old, already look frightful to the experienced eye of an honest stone-cutter.

In regard to the name "Nova Scotia stone", it may be well to explain that it originated many years ago, when grindstone dealers obtained their supplies from some small surface quarries located in and near Nova Scotia. As that stone was of a yellow color, the stone trade has persisted ever since in calling every light-colored stone coming from anywhere in that section "Nova Scotia stone". However, 95 per cent. of the imported stone is derived from New Brunswick (probably 85 per cent. from Dorchester), and the remainder from Nova Scotia and other points. The popular name has been applied to light-colored stones of every quality, quarried at various points of eastern Canada, over a wide section of country, hundreds of square miles in extent, and variously worked out at tide-level, under tide-water, from exposed reefs running out into the sea, or, as at Dorchester, New Brunswick, from a hillside 900 feet high and a quarter of a mile from tide-water. The small quarries usually work out only such stones as they can obtain from outcropping ledges and bowlders, and these are apt to be of bad and varying color, more or less full of iron and other defects; for example, the surface quarries of Hillsboro', New Brunswick, long since abandoned, used in the houses in Forty-second street near Madison avenue, in Second avenue near Fifty-fifth street, some of the bridges in Central park, etc. At the quarries of Dorchester, New Brunswick, it is stated that from 35 to 50 feet of inferior rock and débris are first stripped off to reach the sound rock which is sent to this market. The introduction of this stone into the city as a building material has been too recent to allow any measure of its durability. A little exfoliation may be, however, distinguished near the ground line, and on the sides and posts of stoops, in many cases. Also, in panels, under heavy projecting moldings, cornices, etc., where the sun has no chance to reach and dry up the dampness, the stone molders away slightly over the surface. In the cemeteries it is rarely or never used; in one example, possibly of this material, in Saint Paul's church-yard, (W. J. M., 1841), the decay is plainly beginning around the carvings. The discoloration of good varieties of the stone would be very slow to affect vertical surfaces, properly protected by drips; but on sloping, horizontal, or shaded surfaces, especially near the street-level, street-dust is sure to lodge and cling, all the more after the surface becomes roughened by a slight disintegration; while the rough usage to which the stone of balustrades and stoops is always subjected in a busy street, renders this, as well as all other soft varieties of freestone, liable to chipping as well as offensive discoloration (*e. g.*, in the courses, trimmings, and posts of the church on the corner of Forty-second street and Madison avenue, etc.), and unsuitable for use near the ground line.

These freestones from New Brunswick and Nova Scotia, largely employed in our cities, rarely exhibit a laminated structure, and, though a softer stone than the Triassic sandstone just referred to, is rarely affected by exfoliation to any extent, partly perhaps because its introduction into this district has been much later than that of the brownstone. Many instances occur, however, where already an exfoliation has taken place, especially near the ground line and on peculiarly exposed surfaces, sufficient to mar offensively the appearance of the masonry. This is exceptional it is true, but only a proper investigation or a far longer trial—as yet little exceeding twenty-five years—will establish the fitness of this stone for this climate.

So also the freestone from Amherst, Berea, etc., Ohio, has been used to considerable extent, and in one building (on the corner of Broadway and Barclay streets) has stood well for twenty years. Its rich content of quartz, said to reach 97 per cent. in the buff stone from Amherst, renders this one of the most promising, in regard to durability, of all the freestones of the sandstone class yet introduced here. Buildings constructed of this material in this city since 1857 (*e. g.*, on the corner of Barclay street and Broadway, on the corner of Howard and Crosby streets, etc.), show no decay, but only discoloration. In other instances (*e. g.*, rows of houses on Fiftieth street, west of Fifth avenue, on Madison avenue between Thirty-fourth and Forty-third streets, etc.) the blackened discoloration and frequent chipping of edges of the soft stone are quite offensive. On the other hand, it must be admitted that a stone which cleans itself by the disintegration of its surface, the grains dropping out and so carrying away the dirt, as in the poorer and softer varieties of brownstone or of Nova Scotia stone, is by that very action still more objectionable from its want of durability; and the discoloration of the Ohio stone is offset, at least in part, in the best varieties, by their hardness and promise of durability. Nevertheless, all these light-colored freestones from New Brunswick or Ohio, as well as the light-colored limestones from Indiana, etc., and the light-colored granites from New England, are all open to the special objection of most offensive discoloration (described beyond) shown here in abundant instances as in the cities of the west. This is more likely to affect inclined than vertical surfaces, and those near the level of the street, *i. e.*, within the reach of deposit of street dust; and the objection might be largely obviated by our builders by discarding the light-colored stones of all kinds from projections (cornices, dressings of doors and windows, etc.), and from our stoops, where the additional softness of some varieties renders them liable to disfigurement from wear and blows (*e. g.*, the blocks of Nova Scotia stone fronts in Madison avenue, above Thirty-fourth street).

MEDINA SANDSTONE.—This material is of recent introduction (*e. g.*, Baptist church on Fifty-seventh street, west of Sixth avenue), and its true durability cannot yet be estimated.

BLUE-STONE (graywacke).—This stone is yearly coming into more general use, and, though somewhat somber in tone and difficult to dress, seems likely to prove a material of remarkable durability. In one building in Twenty-fourth street, between Madison and Fourth avenues, its condition appears to be excellent, after fifteen years' exposure perfectly retaining the tool marks. The variety reported to come from the Wyoming valley (*e. g.*, in the building on the north side of Union square) is really derived, as I am informed by Professor H. L. Fairchild, from Meshoppen, Pennsylvania.

The blue-stone or graywacke of central New York and of Pennsylvania has not only been of general use as a flag-stone, but, in compact varieties, has been yearly coming into greater use in our cities for the purpose of water-tables, ornamental bands, window-sills, etc., and, although not a freestone, has recently been introduced even for the fronts of residences (*e. g.*, on northwest corner of Madison avenue and Seventy-second street). It is likely to be one of the strongest and most durable stones, in my opinion, and, to judge by its weathering in outcrops, will be liable, only after a long exposure, to a reddish-brown discoloration.

LIMESTONE.—The Lockport limestone has been used to a small extent in this city, unfortunately for buildings of importance, since it is a loosely compacted mass made up of fragments of shells, corals, etc., extremely liable to disintegration, apparently more from the action of frost than any other cause. To this stone may be applied the observations of Professor F. A. Abel on the fossiliferous bands in the stone of the island of Portland. (*a*)

> Though petrifactions were shown by the results of experiments to impart, in many instances, great additional strength to the stone they frequently give rise by their existence to cavities, sometimes of considerable size, which not only serve to weaken those particular portions of the stone, but may also, if they exist in proximity to exposed surfaces of a block of stone, promote its partial disintegration by the action of frost.

The Lockport stone has evidently owed its rapid disintegration within ten years, wherever used in this city, in part to its careless mode of introduction into masonry. Thus, in the building of the Lenox library, at Seventieth street and Fifth avenue, about 40 per cent. of the material is set on edge, *e. g.*, the alternate receding courses of the ashlar, trimmings of apertures, gate-posts, etc. Consequently it betrayed decay long before the completion, fragments falling out of the face of the stone from the arris of cornices and bands, etc. In the abundant trimmings of the same stone in the building of the Presbyterian hospital in the vicinity the same disintegration is displayed, the surfaces peeling off and filled with fine and deep crevices, and the upright posts, *e. g.*, near the entrance archway or porte-cochère on the south side, in which the bedding-laminæ stand on edge, are already seamed throughout with long cracks, which betoken their steady destruction.

The oolitic stone from Ellettsville and Bedford, Indiana, shows an almost immediate and irregular discoloration, said to be produced by the exudation of oil. The oolite from Caen, France, has also been used in many buildings, and, unless protected by a coating of paint, has shown decay in several instances. Mr. G. Godwin, of London, has stated (*Soc. of Arts*, 1881), that "the Caen stone which was sent to this country (England) could not now be

a The Builder, London, 1863, Vol. XXI, p. 859.

depended on, and ought not to be used for external work". The extensive decay of this, with other oolitic and magnesian limestones, in the walls of Westminster abbey, has recently caused great alarm, and will necessitate the renewal of its outer masonry at enormous expense.

One of the most thorough investigations, in regard to the porosity of a series of American building stones, was made by Dr. T. S. Hunt in 1864, and with the following conclusion (*Chemical and Geological Essays*, p. 164):

Other things being equal, it may probably be said that the value of a stone for building purposes is inversely as its porosity or absorbing power. From the results given on 39 specimens, the following may be here quoted as pertinent to stones used in New York city:

No. of specimens.	Absorption. Percentage.
1. Potsdam sandstone, hard and white	0.50 to 3.96 *a*
2. Medina sandstone	3.31 to 4.04
3. Ohio sandstone	9.59 to 10.22
3. Caen limestone	14.48 to 16.05

Of course the proviso, "other things being equal," covers a great deal of important ground, including the solvency of the material of a stone in the acidified rain-waters of a city. Some of the most impervious and non-absorbent readily decompose; while others, which are porous or even cellular, may afford an excellent resistance to decay. But judged in regard to both points, porosity and solvency, the Caen stone may be safely rejected hereafter as unfit for our climate.

Other limestones, oolitic or fine granular, have been brought into use in small quantity, but remain as yet untested by the conditions of our climate.

GRANITE.—As to granite, its tendency to decomposition, termed the "maladie du granit" by Dolomieu, depends chiefly upon climatic conditions. These differ vastly, it is well known, in this region and in that of the great granite-builders, the Egyptians. The obelisk of Heliopolis has stood for three thousand years, and is still in good condition. So, too, the obelisk of Luxor had stood for forty centuries in Egypt without being perceptibly affected by that climate, but since its transport to Paris, in the reign of Louis Philippe, it is reported as the result of but forty years' exposure—

It is now full of small cracks, and blanched, and evidently will crumble into fragments before four centuries have passed.

We have transported another obelisk, "Cleopatra's Needle", from Egypt, and, in defiance of the still greater dangers incident to our severe climate, have erected it, covered with delicate carvings, upon a hillock in Central park, exposed to our blazing sun, pelting rain, and biting frost, often successively within twenty-four hours—a monument to the public ignorance in regard to the protection of even our prized possessions—that indifference of our community to the practical value of science which was exemplified through its officials by wantonly paving the walks of the same park with the fragments of the restoration casts of Saurians, after their construction for three years by Waterhouse Hawkins. Granite is also found in many other of our larger buildings, both public and private, but as few of these exceed forty or fifty years in age, and all contain the most durable varieties of that stone, the effects of weathering are only beginning to appear. The bluish variety from Quincy, Massachusetts, has been used in many buildings and rarely shows as yet many signs of decay. In the United States custom-house, on Wall street, most of the huge blocks appear laid "on bed", but, nevertheless, show some pitting in places, by the attack and partial removal of the larger grains of hornblende. In the church at Fourth street and Lafayette place, erected in 1830, a little exfoliation has been produced by street-dust on the faces of some steps. In the Astor house, at Barclay street and Broadway, no decay was observed.

In the fine-grained granite from Concord, New Hampshire, employed in the building on the southeast corner of Twenty-third street and Sixth avenue, many of the blocks are set on edge, but the only change yet seen is that of discoloration by street-dust and iron oxide from the elevated railway.

The light-colored and fine-grained granite of Hallowell, Maine, has been used for the construction of the city prison, the "Halls of Justice" or "Tombs", in Center street. This stone consists of a white feldspar, which predominates, a grayish-white quartz, which is abundant, and a considerable quantity of a silvery white mica, thoroughly intermixed. The rock possesses several properties—fineness of grain, homogeneity of structure, and freedom from iron, as shown by the color of the feldspar—likely to render it durable; the only unfavorable conditions are the predominance of feldspar and the laminated structure. The rock is a granitoid gneiss, with lamination often clearly marked; these markings at once show to the eye that most of the blocks are set, not on bed, but irregularly on edge.

The building is square and occupies an entire block. On a study of the weathering the south face was found to present an exfoliation to the depth of from one-eighth to one-quarter of an inch at many points, up to the very summit of the building, particularly on the sides of the pillars at the southeast entrance, on the ashlar near the southwest gate, under and over the cornice and string-pieces. In some places the stone was loosened or peeled off in sheets of the area of a square foot. The west front presents much exfoliation all over the surface, though always thin; it seems to begin chiefly along and near the joints. In places fragments have separated from the corners of the blocks. The north front exhibits very little exfoliation; so also the east front, in a few small scattered spots.

a Usually about 1.

The exfoliation appears to be the result directly of the sun's heat, exerted most intensely on the southern and western sides of the building. An examination of the disintegrated material shows but little decomposition; a little kaolin may be distinguished in films, but the bulk of the feldspar, the weakest constituent, remains with bright facets, without change in color or luster. It is by no means characteristic of the "*maladie du granit*", first described by Dolomieu and later studied by Dr. T. Sterry Hunt; but here the action seems to be mainly and simply a disintegration of the grains, initiated by expansion under the sun's heat, during the summer, and developed by the expansion caused by frost during the winter. An architect of the city recently stated that he had built several large granite offices, and considered Quincy granite the most durable of all building material. He thought the weathering of granite would hardly amount to one thirty-second of an inch in a hundred years. According to that calculation many buildings might hope for a longer span than the thousand years spoken of by the professor.

However, it is a well-known fact that the weathering of granite does not proceed by a merely superficial wear, which can be measured or limited by fractions of an inch, but by a deep insinuation along the lines of weakness, between grains, through cleavage-planes, and into latent fissures. Thus, long before the surface has become much corroded or removed, a deep disintegration has taken place, by which large fragments are ready for separation by frost from the edges and angles of a block. When directly exposed to the heat of the sun an additional agency of destruction is involved, and the stone is suddenly found ready to exfoliate, layer after layer, concentrically. As yet we have little to guide us in the estimation of durability in years, since the best known granite monuments are those which have been exposed to the exceptionally mild climate of Egypt; but even there some exfoliation has been noticed, *e. g.*, on the inner walls of the so-called Temple of the Sphynx.

In the cemeteries within the city and on Long island much granite is now used in slabs and monuments, but its introduction has been everywhere of too recent a date to afford any measure of its durability. Geikie remarks:

> Traces of decay in some of its feldspar crystals may be detected, yet in no case that I have seen is the decay of a polished granite surface sensibly apparent after exposure for fifteen or twenty years. Even the most durable granite will probably be far surpassed in permanence by the best of our siliceous sandstones. But as yet the data do not exist for making any satisfactory comparison between them.

GNEISS.—The oldest building in this city in which this material has been used appears to be that of Saint Matthew's Lutheran church, on the northeast corner of Broome and Elizabeth streets, erected in 1841. The stone is the micaceous gneiss, in part hornblendic, from excavations on the island, with trimmings, string-pieces, etc., of brownstone, the latter, as usual, being in a state of decay. On the west front the gneiss is in excellent condition, occurring in small blocks, mostly laid on the bedding plane. In the south front many of the quoins are set on edge and are much decayed along the joints, sometimes with splitting or exfoliation, fracture of corners, and irregular chipping out of the surface to the depth of one-half to one inch below the level of the projecting cement joints.

SERPENTINE.—This rock has been of limited application as a building material, but the evidence thus far is not in favor of its durability in a city. For example, the serpentine of West Galway, Ireland, called "Connemara marble", has been used both externally and internally in the new museum of Trinity college, Dublin, but "does not withstand the influence of a smoky or gaseous atmosphere". "Small tablets let into the outside wall of the museum have become tarnished within the space of ten years". In Hoboken this stone has been used to some extent for unimportant masonry, and shows in places discoloration and disintegration.

Other stones which may prove to be more durable, and as yet rarely exfoliate, have already, however, become more or less disfigured by discoloration. In the Nova Scotia and Ohio sandstones this is universally seen in black films, streaks, and blotches, of which both the cause and the means of removal are but little understood. The marbles used for house fronts also soon assume a dirty yellow hue. This is sometimes produced by the exudation of salts of iron, as in the walls of the new court-house; sometimes by the adherence of smoke and street-dust. It has been removed by occasional scraping of the whole surface of the building, as has already been done on the old court-house, the new cathedral at Fiftieth street, etc.

2.—EXTERNAL AGENCIES OF DESTRUCTION.

The external agencies which slowly but insidiously and steadily accomplish the disintegration and destruction of our building stones are of three classes, chemical, mechanical, and organic.

A. CHEMICAL AGENCIES.

These chiefly consist of acids which attack and dissolve every constituent of stone except quartz, but, with particular rapidity, any stone into which carbonates enter as chief constituents or as cementing materials. Thus the abundant solution of lime from the stone as well as the mortar of one of our marble buildings may be shown by catching some of the rain-water which trickles down its sides, and adding a few drops of ammonium oxalate, the solution becoming clouded by a milky-white precipitate of calcium oxalate. The following may be enumerated:

SULPHUR ACIDS, *i. e.*, SULPHUROUS AND SULPHURIC ACIDS.—Of these Dr. Angus Smith found in the rain of Manchester from 1.4 to 5.6 grains per gallon. The gases are daily absorbed into the atmosphere of a large city from the consumption of illuminating gas, coal, and all kinds of fuel, the decomposition and oxidation of refuse organic matter and sewer-gas, the residuary gases belched forth from the chimneys of dye works, chemical works, and numerous other manufactories, etc.

As coal seldom contains less than one-half per cent. of sulphur, and frequently one per cent. or more, every ton of coal when burned produces from 30 to 60 pounds of oil of vitriol. When one considers the enormous quantities of coal that are consumed in cities, and the correspondingly great quantities of this corrosive agent that are thus disseminated in the atmosphere, we would naturally expect to find appreciable evidence of its effects on building stones.(*a*)

These effects are likely to be most marked in a large city like London or New York, and on certain stones, *e. g.*, the earthy or oolitic limestones and marbles. In London they are revealed in the magnesian sulphate, which imparts a bitter taste, and even forms an efflorescent crust of white crystals upon the disintegrated portions of the Portland stone, and in the calcium sulphate, amounting to 3.4 to 4.6 per cent. in the decayed crust of the Caen stone. (*b*). Little limestone has yet been introduced into New York, and the durability of a variety in a village or small town elsewhere gives no measure of its fitness to resist the corrosive agencies in the atmosphere of our cities.

CARBONIC ACID.—This is a universal product of combustion, but is indeed derived from all the sources above mentioned, as well as from the respiration of millions of men and animals. Dr. Smith found the air of Manchester to contain 0.04 to 0.08 per cent. of carbonic acid, while that of the highlands of Scotland contained but 0.03 per cent. The researches of Daubrée, T. S. Hunt, and others, have shown the active action which this gas exerts in the corrosion of the feldspar of granites.

NITRIC ACID.—Traces of this acid have been commonly found in the atmosphere and falling rain, but most perceptibly during and after thunder storms. It has been suggested that "every flash of lightning not only generates nitric acid—which, in solution in the rain, acts on the marble—but also, by its inductive effects at a distance, produces chemical changes along the moist wall, which are at the present time beyond our means of estimating. (*c*)

So far as its formation is due to electrical agency, it probably increases during the summer; but it is also one of the products of oxidation of the gases arising from the decomposition of organic matter, ammonia, and nitrates, and from our numerous gas works.

HYDROCHLORIC ACID.—This corrosive agent Dr. Angus Smith found in the rain of Manchester, to the amount of 1.25 grains per gallon. It is derived from the fumes of bleaching works, chemical works, potteries, and many factories, and from vicinity to the sea.

CARBOLIC, HIPPURIC, AND MANY OTHER ORGANIC ACIDS derived from smoke, street-dust, sewer-vapors, etc., have not been hitherto recognized, but, in my opinion, are among the most constant and efficient agencies in the corrosion of the building stones of a city. Whether they are present in the atmosphere and falling rain is still a matter of conjecture, though I think it probable; but no series of analyses has yet been made to determine the exact constitution of the air and rain-water in our cities. However, there can be no doubt of their presence, possibly in the smoke and unconsumed carbon which attach themselves to our rougher stones (freestones, marbles, etc.), certainly in the street-dust, chiefly ground-up horse manure, which is blown against our buildings and remains attached to their surfaces, often to a considerable height above the street level. That the corrosion thus resulting is due not merely to mechanical friction, but mainly to chemical action, is shown by the fact that it is sometimes most active on a surface which is sheltered from the rain, and to which the crust of dust can adhere more persistently. For example, I have noticed that the vertical faces of the steps of Quincy granite beneath the portico of the church on the northwest corner of Fourth street and Lafayette place, perfectly sheltered from the rain, and but little exposed to the wind, have been sometimes covered with a film of street-dust beneath which the smooth-dressed surface of the granite is deeply corroded, peeling off to the touch of one's fingers in flakes from 2 to 5 millimeters in thickness. As to the foundations of buildings, these are exposed to the quiet action of the vegetable acids derived from the decomposition of plants and of the humus of the soil.

OXYGEN.—This constituent of the atmosphere, especially in its more active form, *ozone*, attacks the sulphides (*e. g.*, the pyrite in the Vermont roofing slates and in the marble of Lee, Massachusetts, etc.), and, more slowly, the ferrous silicates in certain minerals (*e. g.*, the chlorite, biotite, hornblende, augite, etc., in our granites, gneisses, traps, etc.). The resulting oxygenation and hydration may be expected to produce expansion and a tendency to loosening of the constituents of a stone.

AMMONIA is another product of animal life and decomposition, the fumes of factories, and atmospheric reactions, whose existence in the air and rain-water has been proved, and which must do its part in the disintegration of stone.

COMMON SALT (sodium chloride) is constantly present in the atmosphere along the sea-board, and must affect the solubility of the cement of porous sandstones, etc. An English observer, however, considers that sea air is not injurious to stone, instancing Sandysfoot castle, near Weymouth, of which the stone is in perfect condition, although erected on the sea-shore and constantly washed by the spray since the time of Henry VIII. A comparison of the forms of decay of stone observed in the cemeteries within this city and in those nearer the ocean, *e. g.*, at New Utrecht, yielded no evidence of any results, attributable to this agency, in greater action at the latter locality.

a C. H. Porter: Paper on Building Stones, p. 24. Albany, 1868.
b J. Spiller, *Rep. Brit. Assoc. Adv. Sci.*, 1867.
c U. S. Commission, 1851.

B. MECHANICAL AGENCIES.

Some of these are probably, in our climate and conditions, the most efficient of all in the wear and disintegration of our building stones.

FROST.—The action of severe frost on stone must be usually one of the main causes of its rapid decay. Two elements are involved—the friability of the material and its power of absorption of moisture. The action may be expected to be most active where a material is repeatedly saturated with moisture, rain-water, or water derived from the thawing of snow and ice, and alternately frozen and thawed. The violence of the force resulting from the congelation of water within the pores of a stone may be understood from a recent estimate, that the effect produced by the freezing in a closed vessel, as it takes place very suddenly, resembles the blow of a hammer of 12 tons weight upon every square inch. However, the disintegration of our brownstones cannot be attributed entirely or mainly to this powerful agency, since the same decay is in progress in southern sea-ports where this brownstone has been used as a building stone; and I have been consulted by a correspondent at New Orleans in regard to the best means to arrest this decay in brownstone fronts there.

On other stones, *e. g.*, marble, this force may exert a very slow action; the experiments of Professor Joseph Henry and the calculations of Captain (now General) M. C. Meigs have shown the depth of exfoliation, after fifty alternations of freezing and thawing by artificial means, to amount to very nearly the ten-thousandth part of an inch. (*a*)

VARIATIONS IN TEMPERATURE.—The constant variations of temperature from day to day, and even from hour to hour, give rise to molecular motions which must affect the durability of the material of a building. Recent observations on the pendulum have shown that the Bunker Hill monument at Boston is scarcely for a moment in a state of rest, but is constantly warping and bending under the influence of the varying temperature of its different sides. (*b*)

The climate of New York must be far more trying than that of England, as the temperature may vary 120° or more in a single year, and even 70° in a single day, with many repetitions of similar extremes during the spring and fall, and sometimes during the winter months. The intensity of the direct rays of the sun, particularly in summer, and the frequent passing showers of cool rain-water falling upon the heated surfaces, are important elements in the attack upon the building stones.

The experiments of Colonel Totten, reported by Lieutenant William H. C. Bartlett in 1832, on the expansion and contraction of building stones by variations of temperature, yielded the following results, for the linear expansion, in fractions of an inch, of one inch of stone for 1° of Fahr.:

Granite bowlder at Buzzard's bay	0.000004825
Marble, Sing Sing, New York	0.000005668
Sandstone, Chatham, Connecticut	0.000009532

To apply these results to the case in question, let us suppose two coping stones, of 5 running feet each, to be laid in midsummer, when they have a temperature of 96° Fahr.; in winter their temperature may safely be assumed at zero, so that the total variation of temperature will be 96°.

The distance by which the ends of the stones would be separated would amount, for granite, to 0.027792 inch, giving a crack a little wider than the thickness of common pasteboard. For marble, this crack would have a width of 0.03264, nearly twice the thickness of common pasteboard; and for sandstone 0.054914, nearly three times the thickness of pasteboard. These cracks are not only distinctly visible, but they allow water to pass freely into the heart of the wall. The mischief does not stop here: by this constant motion, back and forth, in the coping, the cement, of whatever kind the joints might be made, would be crushed to powder, and in a short time be totally washed by the rains from its place, leaving the whole joint open.

WIND.—A gentle breeze dries out the moisture of a building stone and tends to preserve it, but a violent wind wears it away by dashing sand-grains, street-dust, ice particles, etc., against the face. The extreme of such action is illustrated by the vast erosion of the sandstones in the plateaus of Colorado, Arizona, etc., into tabular *mesas*, isolated pillars, and grotesquely-shaped hills, by the erosive force of sand-grains borne by the winds; in the window-panes of houses on Nantucket island, converted into ground-glass by flying sand; and in the artificial process of manufacture by the "sand-blast", carried on in our cities. A violent wind also forces the rain-water, with all the erosive acids it conveys, into the pores of stones, carries off the loosened grains from the surface, and so keeps fresh surfaces of stone exposed.

In this climate, buildings are most attacked by weathering agents on their north, northeast, and east fronts (the very reverse of the conditions prevailing in Great Britain), and, in this view, it is of course important to select stone of the greatest durability for the fronts into which the prevailing wind thus drives the rain, *i. e.*, those on the west sides of the avenues and the south sides of the cross-streets in New York city.

Again, the swaying of tall edifices by the wind, whose amount can only be appreciated by ascent of our church spires during a gale, must cause a continual motion, not only in the joints between the blocks, but among the grains of the stones themselves. Many of these have a certain degree of flexibility, it is true, and yet the play of the grains must gradually increase and a tendency to disintegration result.

RAIN.—The attack of rain on building stones depends upon its solvent action, partly due to the solvent agencies before mentioned, which it conveys, and upon its mechanical effect in the wear of pattering drops and streams

a Joseph Henry, *On the Mode of Testing Building Material.* *b* United States Commission, 1851.

trickling down the face of a building. In dry weather a stone is therefore less attacked, chiefly because the destructive acids cannot penetrate so deeply. The proportion of rainy days, and above all of frequent alternations of dry and rainy days, in any climate must exert a great influence on the durability of stone.

Professor Hull states:

In India, ancient temples formed of laterite—a modern deposit of gravel cemented by lime—are still in perfect preservation. Such examples, and many more which might be produced, all go to prove that even in regions subjected to very heavy periodical rains, provided the air be pure and free from acids, buildings of even friable and calcareous materials are capable of withstanding atmospheric disintegration for a lengthened period. Rains which fall at long intervals, though with tropical violence, do not act so injuriously on stone structures as those less violent but more frequent. (*a*)

CRYSTALLIZATION BY EFFLORESCENCE.—This effect, too, must largely depend upon the climatic conditions—alternations of dryness and moisture—to which reference has just been made. Examples of efflorescence of various salts, sulphates of magnesium, sodium, etc., are by no means uncommon in New York city and vicinity, though more frequently on brick than stone, walls covered with snow-white powdery coatings having been observed in basements of stores in South street, in cellars of residences in West Fifty-second street, etc. The expansion produced by such an exuding crust is likely, slowly but surely, to disintegrate and loosen scales and flakes from the surface of stone.

In an important investigation of this subject by Mr. Wenworth L. Scott, of London, the following results were obtained: (*b*)

Thirty-seven specimens of salt, collected from the surface of various building materials, were determined as follows:

Thirty-one, sulphate of sodium (and traces of other salts).

Three, mainly sulphate of sodium, and of magnesium and aluminium.

Two, mainly sulphate of sodium, with various phosphates and nitrates of sodium and calcium (never over 18 per cent. of the whole).

One, sulphates of sodium and potassium, with small amount of nitrates, and much sodium chloride.

With regard to the preventive means, * * * I cannot help denouncing the too free use of resinous, oleaginous, or tarry matters, as my own experiments have shown me that, in the event of fire, the walls of a building treated with such substances would inflame the moment their temperature was raised to about 200°.

He suggests the prevention of upward percolation of moisture by a seam of asphalt, laid on every wall when 2 to 4 feet from ground, as used in St. James' hall, etc., London. He has cured the efflorescence of sulphate of sodium or magnesium by application of a weak solution of barium chloride.

Sulphate of ammonium has not an injurious effect until it meets with substances capable of converting it into the sodium salt.

Sulphurous acid or sulphite of ammonium exerts no harmful effect, but rather a preservative influence, occurring in too small quantity to produce efflorescence. The process of osmosis in building materials has been greatly exaggerated, and is probably very slow. It is important that mortars should be carefully chosen, that they may not contain efflorescent salts.

PRESSURE.—A large number of experiments have been carried on to determine the crushing weight of building stones, and the strength thereby indicated. However,

It is generally laid down that the compression to which a stone should be subjected in a structure should not exceed one-tenth of the crushing weight as found by experiment. Practically, however, the compression that comes upon a stone in any ordinary building is never sufficient to cause any danger of crushing. * * * The working stress allowed in practice upon ashlar blocks should not exceed one-twentieth of the crushing weight. (*c*)

Nevertheless it may be expected that when an ashlar block has become weakened by weathering, the rapidity of its disintegration and decay may be hastened by the superincumbent pressure, especially if unequally applied by the settling of the foundations.

FRICTION.—This agency of wear most commonly affects pavements, sidewalks, stoops, the facing of piers, etc. It may be derived from the impact of human feet, of wheels, or of the hoofs of animals; the handling of freight; the removal of dirt, snow, and ice; the flow of tidal currents; the blows of the waves of the bay and river, etc.

FIRE.—The fierce trials to which building materials of all kinds have been subjected, in the great fires in Chicago and in Boston, during the last decade, have shown that there are none, not even brick, which can withstand, in the form of thin walls, without warping or utter destruction, the tempest of flame evolved from the great magazines of combustibles gathered on every side in an American city.

It is a remarkable instance of the prevailing ignorance on this subject that there exist many varieties of sandstone (*e. g.*, the buff freestone from Amherst, Ohio, etc.), graywacke, and perhaps other rocks, which possess a fire-proof character that enables them to resist a white heat, as the linings and hearths of iron-furnaces, and which would seem to specially fit them for the ashlar of buildings desired to be fire-proof, or at least the window-sills, etc., of business buildings, storage houses, etc. It must be considered, however, that experiments are highly desirable to

a *Building and Ornamental Stones*, p. 312.
b On Salification, etc., *Jour. Soc. Arts*, 1860, Vol. IX, p. 274.
c *Notes on Building Construction*, p. 6.

determine the character of resistance of these and other stones, not only to the lateral application of flames or radiation of intense heat, when exposed in a building with a backing of brick, but also to the alternations, rapid and violent, of sudden expansion and contraction, produced by the sudden application of cold water from the streams of fire-engines upon the heated masonry. So far as present observations have gone, however, in regard to such sandstones, I see no necessity to reject the abundant materials supplied by nature, and will present additional reasons on a later page.

C. ORGANIC AGENCIES.

These are of a vegetable nature, in their attack upon the materials of building construction on land, and of animal nature in regard to the erosion of submarine walls.

VEGETABLE GROWTHS.—In regard to the influence of lichens on the durability of stone, very opposite views are held. On the one hand, it is acknowledged that, in the case of marbles and limestones, some lichens exercise a decidedly corrosive action, and Professor J. C. Draper, in a paper on the decay of stone and brick in New York city, maintains that the same "minute lichen, *Lepra antiquitatis*, grows with remarkable freedom on such hygroscopic rocks as the sandstones, as any one may satisfy himself on examining the houses on the cross, or east and west, streets of our city". (*a*)

So far as my observation has gone, lichens are markedly absent from the decayed stone-work of this city, and it is probable that the reference applies to some other form of vegetation. Thus they never occur in the church-yards of Trinity church and Saint Paul's chapel, though found abundantly in those of New Utrecht and Flatbush; *e. g.*, three species were distinguished upon a single tombstone (Rutgert Denyse, 1795) at New Utrecht. On their removal, the surface of the stone beneath is not found corroded, but only retains a fresh color.

In a report on the selection of the oolitic limestone used in the houses of parliament in London, the subject has been thus discussed by one of the commissioners:

A question has frequently been raised with reference to the effect of vegetation on the surface of stone-work. By attentively examining the magnesian limestone buildings of this part of the country, it would appear that lichens exercise a sort of pernicious influence. At Bolsover castle, the keep of which seems to be constructed with magnesian limestone, similar to that of Steetley, wherever lichens have vegetated on the exterior of that edifice, decomposition has certainly taken place; and where they were then growing, upon removing them, we found that the surface of the stone, for about one-sixteenth of an inch in thickness, was reduced to a state of white powder. In such instances the lichen seems to possess some inherent power of chemically acting upon the stone; but whether the plant appropriates only the carbon to its own use and leaves the lime and magnesia, or whether it takes up the carbonate of lime and rejects the carbonate of magnesia, is a question of great interest, although it has not yet been investigated by a scientific observer. (*b*)

The opposite view, advocating their beneficial influence, is represented in the following quotations:

Lichens are in many cases a protection from the weather, and tend to increase the durability of the stone. (*c*)

In the report on the selection of stone for the houses of parliament it is stated:

Buildings situated in the country appear to possess a great advantage over those in populous and smoky towns, owing to lichens, with which they almost invariably become covered in such situations, and which, when firmly established over their entire surface, seem to exercise a protective influence against the ordinary causes of decomposition of the stone upon which they grow.

Many blocks of stone quarried at the time of the erection of St. Paul's, in London, but left in the quarries, and now covered by lichens, still retain their sharp edges and tool marks beneath the lichens, while those on the exposed fronts of the cathedral are now moldering away.

The sandstone of Tintern abbey (thirteenth century), in part laminated, is covered with gray and green lichens, and is, for the most part, in perfect condition. In Tisbury church (thirteenth and fourteenth centuries) the ashlar, constructed of calciferous limestone, is, where undecomposed, covered with lichens.

The exact action of the lichens needs investigation, and will doubtless be found to differ widely according to the species and the material on which they grow. Few of our buildings in this district are sufficiently old to present much growth of this kind.

There is another vegetable growth, however, that of the *confervæ*, of which no notice seems to have been taken, but which flourish in damp weather all the year round, in New York and vicinity, upon shaded surfaces of our freestones, often coloring the vertical faces of the steps and the sides of stoops, and the lower portion of the ashlar, near the ground-line, and under the shadow of heavy copings and cornices, especially on the north shaded fronts of the houses on the south sides of the streets. Upon brownstone their eroding influence is shown in the common roughening of the dressed surfaces. Upon the Nova Scotia or Dorchester stone their action is apparently still more active, as shown in abundant instances on the walls and carved work throughout Central park, *e. g.*, the pillars of Albert quarry stone at the head of the steps at the end of the mall, where shaded surfaces are alternately seen colored green with *confervæ*, and again bare and crumbling, at different seasons of the year, and have needed frequent redressing. It may also be remarked that the heavy growth of vines trained up over the fronts of houses, sometimes seen in this city, would be apt to favor such growths and the decay of soft freestones.

The well-known destructive agency of the roots of grasses and higher plants on the durability of masonry is fortunately not a danger to be considered in our American cities.

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a The Manufacturer and Builder, 1872, IV, 170.
b C. H. Smith: *Lithology, or Observations on Stone used for Building*, p. 26. 1845.
c Notes on Build. Const., Part III, 10.

Boring mollusks, sponges, etc.—The serious danger of the attack of these forms of animal life may be illustrated by the following example:

A limestone from Creston, near Plymouth, England, was originally employed in the construction of the Plymouth breakwater, but the boring mollusks (*Pholas dactylus*) so perforated the stone, between high and low water, that it was thought necessary to replace the blocks by granite. (*a*)

Little masonry is yet exposed in our bay and along our river fronts to the attack of these enemies; but the cargoes of Italian marble sunk off the harbor, which have been found thoroughly perforated and honey-combed by such agency, *e. g.*, that of a steamer sunk in 1871, and the similar erosion of the gneiss of Westchester county, along the sound, by marine sponges, as pointed out by Mr. J. D. Hyatt, of the New York Microscopical Society, indicate the dangers which may be in store for the bases of the piers of the New York and Brooklyn bridge, and for the masonry which will be hereafter introduced into our piers and docks. Birds also serve as destructive agencies; the sparrows and other small birds by their droppings deposited in abundance on cornices and projecting moldings, and the pigeons, as in the London Exchange building, by pecking away the cement between the blocks of masonry.

3.—INTERNAL ELEMENTS OF DURABILITY.

The durability of a building stone depends upon three conditions, the chemical and mineralogical nature of its constituents, its physical structure, and the character and position of its exposed surfaces.

A. CHEMICAL COMPOSITION.

In this view the following conditions need consideration:

Solubility.—The presence of calcium carbonate, as in the more calcareous forms of our Westchester dolomitic marbles, and in the earthy limestones (*e. g.*, that from Indiana recently introduced), is likely to render such materials liable to rapid attack by acid vapors. On the other hand, in England pure dolomite is considered extremely durable as a building stone, as is shown, for example, in the Norman part of the Southwell church, in Yorkshire.

The hydrated form of ferric oxide which acts as the cement in all the Triassic sandstones (*e. g.*, the brownstone of New Jersey and Connecticut) is far more soluble, and so may be more easily removed, to the injury of the stone, than the anhydrous or less hydrated ferric oxide predominating in the cement of our Potsdam sandstone and many foreign sandstones, which seem likely on that account to be better resistants to disintegration. The sandstones whose cement is siliceous (*e. g.*, the Craigleith stone of Great Britain, and some varieties, almost quartzitic, of our own Potsdam sandstone in this state) are likely to be the most durable, and hereafter the most sought for, where durability is appreciated, in spite of their difficulty in working and dressing.

Tendency to oxidation, hydration, and decomposition.—In the case of a roofing slate, the presence of a sulphide (*e. g.*, marcasite, more decidedly than pyrite) is likely to be very injurious; in a granite or marble (*e. g.*, the marble of Lee, Massachusetts, in the new court-house, New York city) the results may be confined to the discoloration and less objectionable. Nevertheless there are abundant instances, which yet need investigation, in which the pyrite occurs in a highly-crystalline condition, even in roofing slates, by which it has been enabled to resist decomposition during centuries. If the pyrite is uniformly and minutely distributed in small quantity, its presence may be even advantageous; thus, the marbles of Berkshire county, Massachusetts, when first cut, are cold gray, but by long weathering acquire a tint of exquisite warmth and transparency. (*a*)

The biotite in many of our granites seems peculiarly liable to decomposition, and apparently to the weakening of the surrounding stone. The brown freestones of New Jersey and Connecticut contain everywhere minute scales of biotite, though in much less proportion than that of muscovite, and the freestones of New Brunswick contain similar scales of a chlorite; both minerals in a state of decomposition more or less advanced.

The orthoclase, which largely enters into the composition of the Triassic and the Carboniferous sandstones, and of all the granites in this market, is the feldspar of most ready decomposition. It is found, on microscopic examination of a brownstone or granite, in various stages of alteration, from a mere dimming of its cleavage planes to a cloudy or opaque mass of the usual structure, and finally to a siliceous shelly network, with its interstices filled with iron oxide. In this condition the mineral has lost all its strength and ability to resist either pressure or atmospheric attack, and a stone in which it prevails must have reached the last degree of disintegration and decay.

The albite, oligoclase, and other feldspars are much better resistants to decomposition, and their abundance in granite or sandstone may be an important element in their durability.

Inclosure of fluids and moisture.—The thorough drying of a stone before, and the preservation of this dryness after, its insertion into masonry are commonly recognized as important adjuncts to its durability. But the exact nature of the process of seasoning, and of the composition of the "quarry-sap" thus removed by thorough drying, have never been investigated. The "quarry-water" may contain little else than ordinary well-water, or may be a solution more or less nearly saturated, at the ordinary temperature, with carbonate of calcium, silica, double salts of calcium and magnesium, etc.; in the latter case, hardening results by the drying and an exact knowledge of its nature might throw important light on the best means for the artificial preservation of stone.

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a *Gwilt's Encyc. Arch.*, p. 492.

a *Am. Arch. and Building News*, 1881, X, 13, 17.

Again, water may exist in large quantity in chemical combination in the silicates (*e. g.*, chlorite, kaolin, etc.), or in the hydrated iron oxides which constitute the cement of a building stone. Many hydrates of ferric oxide are known to exist, and of these a considerable number occur in nature, in concentrated form, as ores.

We do not yet know how these or other hydrates of ferric oxide are isolated or mixed in their distribution through the brown sandstones. I have elsewhere (*a*) pointed out the probability that, to a large extent, the red cement of the sandstones of most recent or Tertiary age may be probably referred to limonite or limnite, *e. g.*, those found in eastern New Jersey and to the southward along the Atlantic and Gulf sandy plateau; that of the sandstones of the Mesozoic period to turgite and limonite (possibly in part göthite?), *e. g.*, the brownstones of New Jersey and Connecticut; and that of the bright red sandstones of the Carboniferous and older rocks to anhydrous ferric oxide, *e. g.*, the red freestones of New Brunswick and of Scotland, the red sandstones of Potsdam, New York, etc. However, these distinctions cannot be drawn sharply, and the subject awaits investigation. Changes in the degree of hydration are constantly going on in stones of this character, and the absorption of water may exert a force for expansion and disruption. In regard to the vast amount of water feebly locked up in combinations such as these, the query has been recently offered:

> We venture to suggest, as a subject for careful chemical analysis how far the existence of water or the elements of water, not as moisture, but as chemically combined with lime, magnesia, or other elements in a stone, may render it susceptible to the attacks of frost. (*b*)

The more recent results of microscopic lithology have also established the fact that certain minerals, especially the quartz, in very many of our most common building stones abound in small cavities partly or wholly filled with fluids, viz, water, brine, and liquid carbon dioxide. These cavities vary in size from microscopic minuteness up to a diameter of several millimeters, and are often very abundant, so that a fragment of quartz clouded by them may explode on the application of heat. The varieties of our building stones in which they are known to particularly abound are the following: Brownstone—New Jersey and Connecticut; freestone—Dorchester, New Brunswick; biotitic gneiss and fibrolitic gneiss—New York island and Westchester county; granite—Quincy, Massachusetts, Clark's island, Maine, Mount Beatty, Connecticut, Fitzwilliam, New Hampshire, Saint Lawrence county, New York, etc.

The question of the influence of these cavities on the durability of the rock, when exposed to frost or to the intense heat of the summer sun or to fire, is one that yet awaits investigation. The violent explosions which attend the exposure of granites to fire, as illustrated in the great fires of Chicago and Boston, may imply some connection, in part, with the sudden expansion and rupture of such inclosed fluid cavities; while the similar action of frost seems to be suggested by the interesting paper of Mr. W. E. Hidden on the fracture of quartz with liquid cavities in North Carolina. (*c*)

B. PHYSICAL STRUCTURE.

This varies widely in the crystalline and sedimentary rocks; but three conditions, common to both, will be first discussed, then two confined to the former class, and finally two confined to the latter.

SIZE, FORM, AND POSITION OF THE CONSTITUENT MINERALS.—It has been established that the resistance to compression—and it may be supposed in some degree the durability—of a finely-granular rock exceeds that of a coarsely-crystallized variety of the same. Dr. J. S. Newberry has also pointed out that "mica is soft and fissile, and hence is an element of weaknesss. Where it exists in any considerable quantity the stone is easily crushed and unfit for use".

The scales of mica in a laminated sandstone, *e. g.*, the common micaceous variety of brownstone, lie largely in the plane of lamination, and diminish the strength of the rock when pressure is applied in the direction of the latter plane, *e. g.*, on edge, on account of the feeble adherence between their surfaces and the rock in contact. So also when used as ashlar, the expansion caused by frost tends to produce the first separation along those planes.

However, both in a granite and in a freestone, it is probable that a moderate amount of mica—much more an abundance of a tough and fibrous mineral, like hornblende, augite, fibrolite, etc.—may serve as an excellent binding material, like hair in mortar, and add to the strength of the rock, if uniformly mixed, with little or no parallelism of planes. Peculiarities of crystallization in crystalline rocks or of arrangement of tabular flakes of minerals in sedimentary rocks may also produce a coincidence in the position of planes of stronger cleavage, *e. g.*, of feldspar in granites or in feldspathic sandstones, which will diminish both the strength and durability of a rock. The disintegration of the freestones of the Triassic age is favored by both these conditions—abundance of mica and parallel position of feldspar plates.

POROSITY.—Bischoff has thrown much light on the percolation of water through the interstices and fissures of rocks. Even in the densest crystalline rocks, as trap and basalt, spots of moisture can be discovered on freshly fractured surfaces, generally connected with minute fissures. In the loosely-cemented material of the freestones the percolation must be far more free.

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a On the Geological Action of the Humus Acids, *Proc. Am. Ass. Adv. Sci.*, 1878.
b *The Builder*, 1882.
c *Trans. N. Y. Acad. Sci.*, I, 1882.

The excessive porosity of a building stone thickens the layer of decomposition which can be reached by the acids of the atmosphere and of the rain, and also deepens the entrance of the frost and its work of disintegration. This is illustrated, in the case of brownstone, in numberless instances throughout New York city, in the sills and lintels of windows, the projecting string-courses of stone in brick buildings, the steps of stoops and sills of doors, etc., with their edges rounded, their material pitted, honey-combed, fretted, and furrowed by the ridges of projecting or eroded laminæ, or the whole mass of the stone worn away flush with the front of the house, *e. g.*, in the older brownstone houses of the district styled "Greenwich village", in the Eighth ward, and in the old streets on the east side of the city. Even, too, in houses less than ten years old, the flat ceilings of the porticos, surfaces which appear to be perfectly sheltered from the weather, are peeling away into successively-loosened layers, *e. g.*, in the houses on the west side of Fifth avenue, between Forty-sixth and Fiftieth streets. In all these cases we plainly see the effect both of rain, and, above all, of water, derived from the thawing of the snow which is caught and rests upon the projecting ledge of stone, soaking down into the spongy mass below during the day, and again partially thrust out by the expansion of freezing during the night. With a light-colored stone an unusual and undesirable power of absorption is often indicated by its discoloration in streaks and circular patches. Several kinds of discoloration may be distinguished, all more or less dependent on the absorptive character of the stone. The one consists of a white calcareous efflorescence, very common in new masonry, in blotches spreading around the joints, and doubtless derived by permeation of the stone with solutions of calcium carbonate from the fresh mortar or cement. It appears to be usually of a temporary character, disappearing after a few years. This is sometimes seen in brownstone, but more frequently in the Ohio and the New Brunswick freestones; *e. g.*, in the fronts and stoops of most of the houses first built of that stone in Madison avenue above Fifty-fourth street, etc. Another form of discoloration is due merely to the street-dust and soot which are deposited upon the projections of a stone front. It results in long gray or blackish streaks, running down the front at either end of the window-sills and from below the line of projecting bands and cornices, and as a general blackish-gray discoloration of the surfaces of sheltered moldings of apertures, the pediments of porticos, etc.

The earlier stages of this discoloration may be easily studied in numerous instances among the older buildings constructed of light-colored freestone, *e. g.*, in the houses on the northwest corner of Sixth avenue and Twenty-ninth street, and between Thirty-seventh and Thirty-eighth streets, and in the building on southeast corner of Christopher street and Greenwich avenue, etc.; the sloping window-sills of the orphan asylum at Fifth avenue and Fifty-first street are thus blackened, while the vertical faces of the same stone in the façade are washed clean and uncolored.

A similar discoloration affects most of the varieties of white marble used in our city, *e. g.*, in several buildings on the north side of Murray street, between Church street and West Broadway; in the new court-house on Chambers street; the cornices, sills, and seams of the rusticated stone-work of the Union Dime Savings bank, at Sixth avenue and Thirty-second street.

Another form of discoloration, commonly associated with the preceding in the same light-colored freestones, presents black stains and streaks, whose material has not yet been identified, but apparently consists of manganese-oxide, probably derived from the decomposition of the feldspar and chlorite in the rock. This is of a more permanent and objectionable character, increasing both in extent and depth of color with the age of the masonry. Its progress is most rapid on stone surfaces exposed to the prevailing winds and rains, *i. e.*, the northeast. An illustration of this appears in the church on the corner of Fifty-seventh street and Madison avenue, whose faces fronting the south and west are entirely free from discoloration, while the spire, freely exposed above, is beginning to be tinted all around and from top to bottom.

Other forms of discoloration are shown in yellowish stains on the light freestones, certainly due to iron, and in films of confervous growth, which are green during rainy and damp weather, and become blackish-gray when dry.

HARDNESS AND TOUGHNESS.—Resistance to weathering does not necessarily depend upon hardness, since some soft rocks of peculiar composition (*e. g.*, some steatites, chlorite schists, etc.) are known to withstand atmospheric attack very well. However, a hard material of close and firm texture is, in those qualities, specially fitted at least to resist friction and artificial wear, as in stoops, pavements, sidewalks, and road metal, and the natural friction of rain-drops, dripping rain-water, the blows of the surf, etc. The graywacke and blue-stone of New York and Pennsylvania, is, in the form of flagging, unexcelled for paving, etc.; and no reason is apparent why its thicker beds should not be further applied as a material for ordinary construction. So far as yet introduced for this purpose, within a few years past, it preserves perfectly the arris in dressings, quoins, etc., without either chipping or discoloration.

CRYSTALLINE STRUCTURE.—Experience has shown that the crystalline structure in a stone is a better resistant to atmospheric attack than the amorphous. The following statement is made concerning this characteristic in an oolitic limestone of England:

The Steetley stone is remarkable for its light specific gravity, great power of absorption, and yet extremely durable; its resistance to atmospheric influences may be attributed to its beautifully sparkling crystalline structure, without having any dusty incoherent matter in its formation, the crystals being all well cemented together. (*a*)

a C. H. Smith, *op. cit.*, 32.

It is also well illustrated in New York city in the better class of crystalline building stones, *e. g.*, the granite buildings in Murray, Warren, and other of the older streets, the Astor house, etc., which are not yet perceptibly affected by the tooth of time. The same fact is generally true with the sedimentary rocks also, a crystalline limestone or good marble resisting erosion better than an earthy limestone. Only the oolitic varieties of the latter seem to possess, in that structure, an advantage over those that are entirely earthy or amorphous. The durability of a limestone like that of Indiana, recently introduced into this city, must depend upon these conditions. So, too, the highly-crystalline varieties of the Potsdam sandstone, in New York, Wisconsin, etc., abounding in glittering facets which the microscope reveals to be in part quartz crystals of exceeding minuteness, may be expected to have in that respect a greater likelihood of durability, if well cemented, than the ordinary variety made up of rounded grains.

Tension of the grains.—A crystalline building stone (*e. g.*, granite, gneiss, marble, etc.) is made up almost entirely of imperfect crystals of its constituent minerals (of calcite, in a marble—of quartz, feldspar, etc., in a granite) closely compacted together, originally with intense mutual pressure. Sometimes no cement intervenes, but any two grains remain in close contact at an impalpable invisible line. Such a condition must be sensitive to very slight influences, the surfaces of the grains in a building stone being alternately pressed still more tightly together or separated to disruption, *e. g.*, by variations of temperature, above all at the extremes of severe cold and frost, of burning sunshine, and of fire. A good illustration is found in those marbles which seem to contain no cement in their interstices, *e. g.*, the coarse Tuckahoe marble, which soon becomes seamed with cracks, as in the building on the corner of Thirty-second street and Broadway.

In England it has been found that—

> All varieties of Carrara marble have perishable qualities which ought to preclude them from being ever applied to external purposes in this country. After exposure to the weather for thirty or forty years, disintegration through its entire mass, but mostly on or near the surface, evidently takes place; after the lapse of about a century, more or less, according to the quality of the marble, the entire substance falls into a kind of sparkling sand. (*a*)
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> Frequent changes of temperature also tend to destroy Carrara marble more rapidly than atmospheric influences; thus the mantel of a chimney-piece is invariably disintegrated long before any other part.

Contiguity of the grains.—The principle which obtains in the application of an artificial cement, such as glue, in the thinnest film, in order to gain the increased binding force, by the closest approach of the cemented surfaces, finds its analogy in the building stones. The thinner the films of the natural cement, and the closer the grains of the predominant minerals, the stronger and more durable the stone. One source of weakness in our brownstones lies in the separation of the rounded grains of quartz and feldspar by a superabundance of ocherous cement. Of course, the further separation produced by fissures, looseness of lamination, empty cavities and geodes, and excess of mica, all tend to deteriorate still further a weak building stone.

Homogeneity.—A great difference of the hardness, texture, solubility, etc., in the material of the grains of a rock and of their cement, or of the successive laminæ, renders the weathering unequal, roughens the surface, and increases the sensibility of the stone to the action of frost. So also softer patches, of more easily decomposed veins and layers in the stone, produce unequal weathering, hollows, furrows, and projecting ridges. Even a hard crystalline and otherwise durable stone may be materially weakened by these defects. Illustrations of this are found in the same varieties of the dolomitic marbles, with irregularly mixed constituents, from the old quarries at Kingsbridge, on New York island, and in Westchester county.

C. CHARACTER AND POSITION OF SURFACE.

The rough or polished condition of the surface of the stone, its inclination from a vertical plane, and the position in which it stands with reference to the sun and to the prevailing direction of the wind, all constitute important elements of its durability.

Smooth dressing or polish.—It is generally assumed, and rightly, in the climate of New York, that a smooth or polished surface tends to protect a stone by facilitating the rapid discharge of rain-water from its surface. The present condition of most of our smoothly-dressed granite fronts seems to confirm the general accuracy of this opinion. Nevertheless some anomalies occur. It has been observed in London that, in the modern buildings, decay progresses far more rapidly than in the ancient, and it has been queried whether this may not in some way be due to the application of machinery.

A series of observations by Professor Pfaff, of Erlingen, Germany, in reference to granite, syenite, etc., have shown, among other results, that the superficial loss in a century, by exposure to the weather, may amount, on unpolished granite, to 0.0076^{mm}, on polished granite to 0.0085^{mm}.

These conclusions in regard to the more rapid weathering of polished granite yet need confirmation by more extended observations in other localities. But an investigation is yet needed to determine whether the vibration of the surface of a stone, produced by the jar of the machinery employed in sawing or polishing, as well as the bruising produced by the friction of the sand, diamond-saws, etc., and still more, the strain and pressure produced by the impact of the blows of chisel and hammer, in smooth and rough dressing, do not produce superficial changes of tension, minute fissures produced by the separation of surfaces of feeble adherence (*e. g.*, on smooth planes of

a Gwilt's *Encyc. of Arch.*, p. 491.

tabular flakes of feldspar, scales of mica, etc.), cracks in brittle minerals (*e. g.*, quartz), microscopic clefts along cleavage planes (*e. g.*, of the feldspars), slight disruption of grains from the adhering cement, etc. If these actions do occur in stone-working, and especially if they reach a sensible depth, as I believe, they may partly account for the anomalous loss of polish and rapid peeling away of successive layers from the surfaces of dressed granites and freestones. The very dressing, so agreeable to the eye, may actually present the surface of the weaker stones in the worst possible condition to resist atmospheric attack.

On the other hand, a roughness of the surface favors the deposition of street-dust, smoke, etc. In France—

> The beautiful marble sculptures of the park of Versailles will, within the next fifty years, become, through its means, unsightly and ugly masses of dirt, and eventually be irretrievably lost. Dr. Robert recently called attention to the fronts of the Bourbon and Mazarin palaces, that of the legislators, the mint, and others, which by this influence are hastening to decay, and even more rapidly in proportion as the ornamental carvings promote the deposition of dirt and dust. (*a*)

It has been shown that in New York these substances have been observed to exert a deleterious influence by chemical corrosion of the stone on which they rest. Being chiefly organic in material and absorbent of moisture they also furnish a suitable nidus for the growth of minute plants, *e. g.*, lichens, *confervæ*, mosses, etc., whose erosive action has been already mentioned. However, there is no doubt that under certain circumstances, not yet understood, a crust of dirt, smoke, and soot may act as a preservative to the stone, as observed by E. C. Robins and A. Billing, on St. Paul's and on Hanover chapel, London, on the church of St. John's, in Southwark, etc.; the same is true also of at least some of the vegetable growths—certain lichens which flourish in the dusty deposits.

INCLINATION AND POSITION.—Sufficient reference has already been made to the influence of these conditions in many ways on the durability of stone. The illustrations are without number throughout the older streets of our city, in the decayed state of those surfaces of stone which are horizontal, and on which rain-water, slush, snow, and ice may rest; of those on the south side of cross-streets, and the west side of the avenues running north and south, which are exposed to the driving rain of northeast gales, etc. Thus, in the towers of the church on the northwest corner of Clinton and Pacific streets, Brooklyn, the brownstone on its front, which faces the east, is peeling off in patches in many places, while the south face of the towers remains apparently unattacked.

Again, on surfaces which are liable to be water-soaked, but which may be sheltered from the sun and wind, the moisture does not quickly dry out, and here especially the decay may be very rapid. The soffits of arches and lintels, the shady sides of window-jambs, and the shady parts of carvings, etc., are among the first portions of a building to decay. From this cause, or from the leaking of a rain-water leader, the surface of a whole pilaster may peel off, as in the building on the southeast corner of Eighteenth street and Fourth avenue, New York.

METHOD OF POINTING OF MASONRY.—The admitted energetic agencies of decay—frost, solution, hydration, etc.—have been largely favored by the imperfect and hasty construction of the masonry throughout the city, its joints when new often admitting a trowel. A cement-mortar of poor quality is largely employed, and, soon dropping out, the joints are often allowed to remain open for years. The atmospheric attack is thus made, as it were in flank, directly through the exposed edges of the outer laminæ of the stone, and the decay rapidly affects the stone to a considerable depth, several inches in many cases, and even throughout the entire block, although the exfoliation may appear superficial.

ERECTION ON EDGE OF LAMINATION.—Instances are very rare in this city where the stone has been laid "on its bed", with a deliberate regard to its durability: *e. g.*, a few houses on Fifth avenue above Fifty-first street, the new wings of the Astor library, etc. On the other hand, from mere convenience in construction, many buildings, especially of our older churches, are fortunately so constructed, the blocks having been small and square and conveniently so laid. In some instances (*e. g.*, the church on the southeast corner of Thirty-fifth street and Fifth avenue) blocks occur in both positions and in both are affected by incipient decay; in others (*e. g.*, the church on southwest corner of Twenty-first street and Fifth avenue) the blocks, although all on bed, are often deeply decayed. In the old city hall, erected in 1812, the north face, although on the side usually least affected by decay, presents the brownstone of its ashlar set on edge and exfoliating in entire sheets, often traversed by fissures across the lamination, parallel to the joints. Notwithstanding these warnings, most of our newest edifices exhibit the same faulty construction: *e. g.*, the sandstone (from Massachusetts) in the trimmings and even partly in the pillars of the Union League Club building, on Fifth avenue, the fine new residences in the upper part of Madison avenue, the trimmings etc., in the huge new buildings for "flats" and business offices throughout the city, often nine to eleven or more stories in height, in whose walls the crushing force exerted upon this soft stone must be excessive.

EXPOSURE TO THE SUN.—Again, subjection to wide differences of temperature on different faces, *e. g.*, those produced by the burning heat of our summer sun on the western faces of buildings, renders the stone liable to crack from unequal contraction and expansion, and produces, on a laminated rock, separation along the planes of lamination, and, on a compact rock, an exfoliation in concentric crusts allied to that of common occurrence in nature on outcrops or bowlders of granite and trap. The former is abundantly illustrated in the marked decay and splitting observed on the western faces of the tombstones in Trinity church-yard, the cemetery at New Utrecht, etc., described beyond. The ashlar at the base of the steeple of the church at Thirty-seventh street and Fifth avenue is beginning to decay on the south side, but not on the north or east sides (the west side not being visible). Other examples are

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a *Manufacturer and Builder*, 1871, III, p. 150.

seen on the brownstone stoops of our cross (east and west) streets, where the western face of the dark stone is rapidly disintegrated and exfoliated, while the eastern face remains much longer in perfect condition. The stone balusters of the balustrades of balconies and the sides of high stoops are, from their slender form, peculiarly sensitive; they disintegrate and exfoliate rapidly on their sun-exposed sides, and become split, ragged, and reduced within five years to a wretched condition, especially when the bedding plane is exposed to the sun. Little rule is observed by stone-cutter or builder in regard to the position of planes of bedding in work of such delicate character as the stone rails, balusters, and posts of stoops and balconies, the planes lying and facing in every direction, sometimes uniform in a particular stoop, sometimes differing—vertical, horizontal, or even sometimes oblique, and directed to all points of the compass—though in general the planes are vertical in the balusters of a stoop and stand either parallel or perpendicular toward the front of the building. The decay is much more rapid in the coarse brownstone, though apparent on the light-colored freestones, and affects the western side of balusters on the cross-streets and the southern side on the avenues. It seems to be somewhat delayed wherever the edges of the layers happen to face toward the sun, *i. e.*, to the west on cross-streets and to the south on avenues, in New York city.

In general it may be stated that all the influences of driving winds, acid vapors, pelting rains, burning sun, etc., are less destructive by far than the quiet action of rain-water or thawing snow dripping and soaking down continuously from any projection or hollow in which water or snow may lodge. A good illustration is found in the synagogue on the southeast corner of Sixty-third street and Lexington avenue, in the fresh, unaltered condition of all its vertical faces of light freestone, and the extensive discoloration which has attacked the face of the pediment of its front portico from water soaking through its roof, and the discolored streaks which run down the inner corners of its towers.

4.—METHODS OF TRIAL.

The methods now in vogue are to a large extent so superficial and empirical, so unsatisfactorily confirmed by the practical results attained, as to have elicited from many an opinion akin to that expressed by a member of the London Society of Arts. His impression was, and it was borne out by the opinions of many practical men, "that when a stone was once out of the quarry it was almost impossible to say whether it was a good stone or a bad one". It has long been recognized that there are two ways in which we can form a judgment of the durability of a building stone, which may be distinguished as the natural and the artificial.

A. NATURAL METHODS.

These must always take the precedence wherever they can be used in any locality, because they refer, first, to the exact agencies concerned in the atmospheric attack upon a stone, and secondly, to long periods of time far beyond the reach of artificial experiment.

A memorable investigation, in which the main dependence was rested apparently upon this class of methods, was that instituted by the British parliament in the royal commission appointed in 1837 for the selection of the stone to be used in the houses of parliament. This commission consisted of four persons: the architect, Sir Charles Barry; two geologists, Sir Henry De La Beche and Dr. William Smith; and Mr. C. H. Smith, a practical man, well acquainted with the working of stone, occasionally assisted by Dr. Buckland and Professor Phillips, and, in the chemical department, by Professors Daniell and Wheatstone. From the study of the outcrops in neighboring quarries and the weathering in several old buildings in Yorkshire, the commission recommended the use of the stone from the Norfal quarries, North Anston, ten miles east of Sheffield, and were discharged. The execution of this recommendation was put in incompetent and irresponsible hands, without government superintendence. Consequently the stone of the Norfal quarries having been adjudged too small for the purpose, and also those of a neighboring quarry, resort was finally had to a stone not covered by the report of the commission, and of this the houses of parliament were mainly erected in 1840. It proved of such inferior character that the decay, immediately setting in, attracted attention even in 1845, and has since led to extensive and costly efforts for the purpose of repair and preservation.

EXAMINATION OF QUARRY-OUTCROPS.—Much information of the highest value may be obtained, especially in the northern United States, where the results of ancient decomposition have been planed off by glacial action, from a study of the old natural exposures of a stone to the atmosphere at or near the quarry from which it was taken, with allowance for the conditions which may there prevail at present, or which probably existed in preglacial time. However, it has been pointed out that "the length of time they have been exposed, and the changes of actions to which they may have been subjected, during, perhaps, long geological periods, are unknown; and since different quarries may not have been exposed to the same action, they do not always afford definite data for reliable comparative estimates of durability, except where different specimens occur in the same quarry". (*a*) Within the district allotted to this report only three building stones are found in place: The trap of the Palisades and of Staten island, whose exposed surfaces are almost always smooth, and whose crust of disintegration, rarely reaching a half inch in thickness, implies a power of excellent resistance to atmospheric attack; the gneiss of New York and Long islands, which often becomes deeply discolored along some planes, but even then, in its common siliceous variety, retains most of its toughness and strength; and the dolomitic marbles of the old quarries of Kingsbridge

a Report of Commission to Test Marbles for the Extension of the United States Capitol, p. 589, 1851.

and Morrissania, no longer worked, and of Westchester county, in which a wide variation is shown on the exposures, some surfaces being disintegrated to a pulverulent mass or loose sand, while others remain firm and hard.

EXAMINATION OF OLD MASONRY.—A study of the surfaces of old buildings, which have been exposed to atmospheric influences for years or centuries, is one of the best sources of reliable information concerning the durability of stone, and frequent references to such observations have already been made in this report; unfortunately no buildings of great antiquity have resisted the iconoclasm of our period and remain for study. Following, however, the example of Professor Geikie, of Great Britain, in his study of a grave-yard of Edinburgh, I have made some studies in those of New York and vicinity. It may be remarked that the varieties of stone used in cemeteries for the dead are usually for the most part identical with the building material employed in the houses of the living at the same period. Nor could any method be devised for testing so thoroughly, by natural means, the elements of durability in any stone as that by which, in the form of a tombstone, it is inserted partly in the moist earth, entirely exposed above to the winds, rain, and sun on every side, with its bedding lamination standing on edge, and its surface smoothed and polished and sharply incised with inscriptions, carvings, and dates, by which to detect and measure the character and extent of its decay.

The present edifice of Trinity church was constructed during the years 1841–'46 (the first building having been erected on that site in 1696). Saint Paul's chapel was erected in 1766, and, although this structure is older than that of Trinity, its cemetery is much more recent in its origin.

Trinity church-yard, New York city.—A variety of materials is found in the tombstones of this cemetery, one of the oldest inclosed in the city. The observations made on the present condition of the stones have been grouped together according to the material, disregarding as carefully as possible all stones which showed evidences of repair and recutting. Most of the stones are erect, and stand with their planes in the meridian, *i. e.*, their inscribed faces fronting the east.

Red sandstone, compact, hard, and fine-grained, apparently identical with that of the church building, and forming the largely predominating material for the stones: Tomb of Matthew Daniel (1820), west side split off, but general condition otherwise good, and inscriptions sharp; also, several tombstones in vicinity in same condition, with more or less splitting along lamination on their western faces, *e. g.*, those of John Child (1808), John Wilson (1805), Peter B. Ustick (1791), Jane Slidell (1770), John Waddell (1762), Joseph Penn (1763), Charles Burleigh (1757), and many others; tombstone of children of John and Mary Bard (1796), much eroded, and splitting on both sides. Two of the oldest stones, those of Jeremiah Reding (1722) and Richard Churcher (1681), are in very fair condition, the inscriptions being sharp, and only a slight tendency to splitting beginning to show on the west side of the top of the stone.

Graywacke or blue-stone, probably from the Catskills or central New York: Tombstone of Remington Stephenson (1730), in excellent condition, but west side beginning to decay; that of Mary Corrin (1730), perfect on both sides; inscriptions sharp on both stones.

Black slate, probably imported: Tombstone of John Daley (1774), in very good condition, only a slight decay roughening the west side; that of Anne Churcher (1691), both faces and edges perfect and the inscriptions sharp.

Gray slate, perhaps from the Catskills: Tombstone of George Carpender (1730), inscription sharp, slight erosion on west face.

Green hydromicaceous schist, probably from western part of Connecticut or Massachusetts: Tombstone of Joshua Amy (1742), in excellent condition, only the west face being slightly worn.

White oolitic limestone, fossiliferous, probably imported from England: Tombstone of John and James Searle (1736), in excellent condition.

Fine white marble, apparently from Carrara, Italy: Inscription and date obliterated, full of minute cracks on both faces.

White marble, probably from western Massachusetts: Tombstone of Lars Nannestad (1807), and that of Alexander Hamilton (1804), both in fair condition, but worn on the north face.

Saint Paul's church-yard.—One variety of fine-grained sandstone predominates, dating from 1813 back to 1768. The finest-grained and most compact are often in perfect condition (J. J., 1768), but many coarser or more laminated stones, and sometimes fine and compact stones, are very badly split, and show exfoliation near the ground (A. Van B., 1813), sometimes with fissures across the stone (J. A., 1813). The splitting begins, as usual, near the west face and near the edges.

As to marble, the stones here date from 1851 back to 1798, and consist of a coarse white marble. It weathers grayish-white, and becomes roughened. Only a small proportion of the stones are split. About one-tenth have their inscriptions entirely obliterated, and this fact, due doubtless to the acid rain-waters of the city, was not observed in the suburban cemeteries; in one case (A. W., 1851) it has been largely affected in a little over thirty years.

The old Dutch cemetery at New Utrecht, Long island.—At this little village, which lies on the southern outskirts of Brooklyn, most of the tombstones are erect, in good condition, and face the east. The materials used are the following:

Fine-grained sandstone, of a warm red to reddish-brown color, resembling the stone of Little Falls, New Jersey. As a rule the stones of this kind are in excellent condition, especially in proportion to their fineness of grain, and universally preserve the sharpness of their inscriptions. Their dates observed range from 1812 back to 1743, and out of twenty-five noted the following may be referred to: Jacques Denyse (1811), very fine-grained, inscriptions and tool marks perfect; John Van Duyne (1801), in perfect condition; Rutgert Denyse (1795), very fine-grained stone, inscription remarkably perfect, even to the finest flourishes; Jacques Denyse (1791), in good condition, a small fragment lost from top edge; Jacobus L. Lefferts (1785), very fine-grained, and in perfect condition; Abraham Duryee (1743), stone perfectly preserved.

Graywacke, light gray, and thinly laminated: S. Barre (1852), stone split throughout, especially on the west face.

Blue marble: Catharine Groenendyke (1797), stone in excellent condition, hard and smooth on the west face, but slightly roughened and pulverulent on the east face.

Mottled black and white marble: Mercy Grenendyck (1794) and Nicholas Grenendyck (1795), in perfect condition in both form and sharpness of inscription, the west undressed face being hard, but the surface of the east face, top, and sides being somewhat roughened and pulverulent.

Red laminated sandstone, probably from New Jersey: W. W. Barre (1854), the east face in perfect condition, but the top and west face beginning to split; Cornelius Van Brunt (1850), the faces in good condition, but a fissure in the lamination behind the east face; Ann Schenck (1824), stone split along the lamination next the west face, and also with a vertical fissure across the lamination of the stone near and parallel to the north edge; William Barre (1826), and Rebecca Johnson (1821), a stone with alternating red and gray laminæ (like that used in the Flatbush cemetery), thoroughly split up throughout, along the lamination, and with fragments lost from the top.

White marble, rather fine grained, and for the most part from Vermont, stones dated from 1847 back to 1828, with usually their inscriptions perfect (for example, the stone of Thomas Clark, 1831), their west faces in good condition, but their tops, sides, and east faces more or less roughened and pulverulent; the stone of J. Lefferts (1828), is in good condition except on the west face, which is much split, apparently by the sun.

Granite from Quincy, Massachusetts, and Aberdeen, Scotland, in a few stones dating only from 1876 back to 1856, and of course in perfect condition. The varieties of stone have been arranged above in about the order in which they seem to have come into general use. In regard to their durability it may be stated in general:

1. The fine-grained red sandstone, probably from Little Falls, New Jersey, has presented a remarkable resistance to weathering, always proportioned to its fineness of texture, generally in excellent condition after a period of more than a century.

2. The laminated sandstone, brought later into use, has been a poor material, yielding miserably, apparently to the heat of the sun, in less than a half century.

3. All the marbles used have resisted the sun in almost every case, but show by the roughened, pulverulent condition of their sides and eastern faces that their decomposition is slow but gradual, and only a question of sufficient though perhaps long time.

A point of difference between the stones of this cemetery, in an open country village on the outskirts of Brooklyn, and those of Trinity church-yard, in New York city, is shown in the abundance of lichens which are found in the former. Three varieties seem to occur: one, a bright green, confined in its growth to the top of the stones; another, of orange color, scattered over the upper part of the west face, exposed to the afternoon sunshine, and rarely seen on the east face; and another of light green color, abounding as a crust over the east face. No particular effect of corrosion by these growths was noticed, either upon sandstone or marble; on their removal the surface beneath was found to be fresh, and had apparently been only protected from weathering.

Flatbush cemetery.—In the old cemetery of the village of Flatbush, Long Island, on the northeastern outskirts of Brooklyn, the tombstones are nearly all vertical, and face the east. White marble predominates largely, but the oldest stones consist of sandstone.

Red sandstone, usually very fine grained and compact, and apparently the variety from Little Falls, New Jersey. The stones vary in date from 1804 back to 1754: Rebecca Suydam (1797), and Marrytie Ditmarse (1797), both faces of these stones in excellent condition; Hylletie Martens (1779), a light reddish-gray stone, in good condition, only the top being a little roughened; Abraham Lott (1754), the inscription perfect, and only a few fragments chipped from the top.

Red laminated sandstone, often very fine grained, largely made up of two materials, reddish-brown and light reddish-gray, in thin alternations from one-half to 1 inch thick. The stones vary in date from 1822 back to 1754: Maria Allen (1820), with sharp inscription, but many fissures in the lamination; Peter Neefus (1820), the stone in excellent condition, covered with sections of long cylindrical markings, perhaps fucoidal; Leffert Lefferts (1800), the stone traversed by fissures along the lamination, and also vertically across it in lines parallel to the edges and about an inch from the edge; Adriantie Lefferts (1761), like the preceding; Gelijam Cornel (1754), decidedly laminated in structure, but in excellent condition.

Tremolitic white dolomite marble, perhaps from the old quarries of New York and Westchester counties, fine-grained to quite coarse in texture, and often sprinkled with grains and flakes of tremolite, sometimes several inches in length. The stones vary in date as follows: E. Aldworth (1851), the stone facing westward, and with minute fissures abounding over the top and the southern edge; A. Lloyd (1847), the stone in good condition, still retaining most of its polished surface, even on the tremolite; J. F. Neefus (1847), surface of stone rough and pulverulent, so that the rough, gray appearance usually distinguishes stones of this material from some distance; Mary Van Siclen (1832), the top and west face roughened one-third of the way down, the remainder being much less roughened; W. Riley (1811), smooth for a height of about a foot from the ground, and roughened above.

Fine white marble, probably of Carrara, the stones varying in date from 1859 to 1801; E. Duclois (1836), somewhat rough and pulverulent all over the surface; N. R. Cowenhoven (1809) and J. Vanderbilt (1801), both horizontal tablets, more or less blackened in spots by a minute lichen (probably the *Lepra antiquitatis*), etc.

Fine white marble, sometimes with gray streaks, probably from Vermont; the stones are of recent date, from 1855 to 1730: Charity Van der Veer (1836), the entire surface of the stone pulverulent, rubbing easily off into fine sand; Femetie and Peter Stryker (1730), roughened down to a foot from the ground, where the polish remains.

The lichens abound here also on the tops of the stones, but have been mostly cleaned off their faces. The same general conclusions may be here deduced, in regard to their durability, as in the similar varieties observed at New Utrecht. It is a curious circumstance, in all these cemeteries, that the stones display no exfoliation or decay near the ground, the polished surface often remaining perfect; above, the action of the sun on the western faces, and of northeast storms on the eastern faces, are apparent as usual.

B. ARTIFICIAL METHODS.

The various text-books on building-construction describe in detail many methods of trial of building stone; *e. g.*, of solubility in acids; of absorptive power, by soaking in water and determination of increase of weight; of power to resist the expansion due to frost, by actual freezing, or by saturation in saturated solution of sodium-sulphate (Brard's method); of strength to resist crushing, bending, or tension, by the application of pressure or force in various ways, etc.

It is unnecessary to make any reference here to these descriptions, except in regard to their antique and unsatisfactory character, and to the apparent ignorance of the appliances now within the reach of students of the modern science of lithology, which can readily be used to reveal the true nature of a building stone and the elements of its durability, *e. g.*, the study of its surface under the microscope, or of slices ground so thin as to be transparent, or of its individual mineralogical constituents separated by means of their difference in specific gravity, or by means of the almost endless resources of micro-chemistry. The careful and well-digested circular of the department of building stones, issued by the late curator of the National Museum, Mr. George W. Hawes, whose recent decease has been universally deplored as a great loss to science and to the work now in progress in this field, has given a suggestion of the wide departure from the old and incomplete methods which is at last called for, in order to advance our knowledge of the proper application and practical use of building stones, under the light of modern discovery.

One important method, long in use, is the determination of the absorptive powers of a stone. A granite which absorbs water to over half of 1 per cent. of its weight is open to the suspicion of doubtful durability. Similar caution needs to be observed in the choice of freestones in our own climate.

Any sandstone weighing less than 130 pounds per cubic foot, absorbing more than 5 per cent. of its weight of water in twenty-four hours, and effervescing anything but feebly with acid, is likely to be a second-class stone, as regards durability, where there is frost or much acid in the air.

It is here pertinent to refer briefly to some significant results obtained by Professor John C. Draper, of this city, in experiments on two of our most common building stones, in comparison with brick.

Fragments of each of the materials were soaked in a saturated solution of sodium sulphate for four hours, then allowed to dry and crystallize for twenty hours, then freed from loosened material by washing off by means of a fine jet of water from a wash-bottle. This operation was repeated eight times, *i. e.*, eight days, with the following results, the first column of figures representing the loss of substance, by weight, in 10,000 parts:

	Loss.	Ratio.
Nova Scotia stone	441	18
Brownstone	191	8
Red brick	74	3
White brick	24	1

As Professor Draper has pointed out, these results only tend to show that frost is not the main agent of the initial disintegration in the climate of New York, since it is not the Nova Scotia stone, but the brownstone, which suffers the most severely and rapidly from decay.

A quicker method employed was to heat the specimens to a temperature of about 600° Fahr., and quench them, while hot, in cold water. This method of trial yielded the following comparative results:

	Loss.	Ratio.
Nova Scotia stone	597	14
Brownstone	202	5
Red brick	82	2
White brick	43	1

These results appear very significant, especially in relation to the power of brick and stone to resist the destroying action of great conflagrations.

Again, to determine the extent of the action of acid vapors in the air upon the building stone, fragments of the same materials were digested in dilute acids, and the following results were obtained:

	Loss.	Ratio.
Brownstone	216	30
Nova Scotia stone	66	9
Red brick	33	5
White brick	7	1

On this subject Professor Draper remarks:

From this it would appear that the reason the brownstone disintegrates so rapidly in our city is its greater susceptibility to the action of the acid products of organic decomposition and combustion; where the cementing material is dissolved or weakened, and pores and fissures in the rock being opened, it is less liable to resist the attack of frost. The Nova Scotia stone, on the contrary, is a more friable material than the brownstone; yet, being less acted upon by the acid waters, it resists the process of decay better.

On the other hand, Dr. Page has obtained the following results, by Brard's process, on 1-inch cubes of several building stones used in this city, which do not confirm Professor Draper's results:

Variety.	Locality.	Specific gravity.	Loss in grains.
Coarse dolomitic marble	Pleasantville, New York	2.860	0.91
Close-grained sandstone	Little Falls, New Jersey	2.482	0.62
Coarse-grained sandstone	Connecticut		14.36
Fine-grained sandstone	Connecticut	2.583	24.93
Coarse-grained sandstone	Nova Scotia	2.518	2.16
Light dove-colored sandstone	Seneca, Ohio	2.456	1.78
Hard brick		2.294	1.07
Soft brick		2.211	16.46

Many experiments have been made to determine the crushing strength of building stones, an element which probably bears some relationship, at least in a general way—exactly what, it has never been determined—to their durability. The results in regard to the building stones used in New York, according to various authorities, are given in table on pages 330–335. They have been collected from various publications, mainly the reports of 1874 and 1875, by General Q. A. Gillmore, on the compressive strength, specific gravity, and ratio of absorption of the building stones of the United States, and a report of the results (communicated to me by Mr. F. R. Collingwood, an engineer of the New York and Brooklyn bridge) of the trials by Mr. Probasco, of the dock department of this city, on the stones employed in the bridge. A point yet needing investigation, but apparently as yet disregarded, is whether the crushing strength of a stone, as determined on the bed, may be affected, possibly diminished, by the reversal of its original position; a fact probably of common occurrence, since the original top of a block is rarely marked.

Other experiments have been made, too limited and imperfect for quotation here, such as those by Professor Joseph Henry and the United States commission in 1851, and by Professor Walter R. Johnson in 1852, to determine the amount of material thrown off from American marbles, etc., by repeated freezing and thawing, etc.

In this connection we may refer to the experiments made by Dr. Hiram A. Cutting, of Vermont, on a series of American sandstones, in regard to specific gravity, weight, absorptive power, and resistance to fire. The results on varieties like those used in New York city are quoted in the following table (*The Weekly Underwriter*, 1880, Vol. XXII, p. 288):

Local name.	Locality.	Specific gravity.	Weight of one cubic foot.	Ratio of absorption.	Heated at 600° F.	Heated at 800° F.	Heated at 900° F.	Heated at 1,000° F.	Heated at higher temperatures.
			Pounds.						
Freestone	Portland, Connecticut	2.380	148.7	1 + 27	Not injured.	Not injured.	Friable	Tender	Ruined.
Freestone	North of England	2.168	135.5	1 + 27	do	do	Cracks badly	Spoiled	
Montrose stone	Ulster county, New York	2.661	166.3	1 + 314	do	do	Not injured	Slight injury	Stands well.
Freestone	Belleville, New Jersey	2.350	146.8	1 + 27	do	do	Cracks	Friable	
Freestone	Nova Scotia	2.424	151.5	1 + 240	do	do	do	do	
Carboniferous sandstone	Br. Philips, Nova Scotia	2.353	147.0	1 + 19	do	do	Crumbles	Cracks and crumbles.	
Freestone	Dorchester, New Brunswick	2.303	147.7	1 + 26	do	Cracks	Cracks and crumbles.	do	
Berlin stone	Cleveland, Ohio	2.210	*138.1	1 + 22	do	Not injured.	Slight cracks		Stands well.
Berea stone	Berea, Ohio	2.254	140.8	1 + 20	do	do	do	Crumbles	Do.
Amherst stone	Amherst, Ohio	2.200	*137.5	1 + 18	do	do	Changes color	Friable	Do.
Brownstone	Hummelstown, Pennsylvania	2.346	146.6	1 + 28	do	do	Cracks	Crumbles	
Potsdam sandstone	Beauharnois, Quebec	2.512	157.0	1 + 38	do	do	do	do	

* It is claimed that these figures understate the true weight, which is said to approximate 155 pounds.

5.—MEANS OF PROTECTION AND PRESERVATION.

We have next to consider, first, the natural principles, very commonly neglected, which should be considered in the construction of stone buildings in the climate of New York city, and, secondly, the artificial means which may yet be applied for the preservation of our crumbling edifices.

A. NATURAL PRINCIPLES OF CONSTRUCTION.

These may be simply divided as follows:

SELECTION.—British architects have sometimes become so discouraged at their ill-success in fighting the elements for the safety of the materials they employ in construction, that the recommendation has been made to discard the soft freestones commonly in use, and resort entirely to the "igneous rocks", so called, in polished blocks, *e. g.*, granite, basalt, serpentine, etc.

Mr. C. H. Smith, one of the commissioners on the houses of parliament, makes a statement (*a*) which is as applicable in the latitude of New York as in that of London.

The chief cause of defective stone being used rested with the architects. A young architect would like to make as much display as he could for little money. To make a great show, he used a cheap description of stone. It was generally put into the contract that the best materials only should be used, but it might be a question whether young architects, or even old practitioners, knew what was really good stone, and they would not apply to those who did. The builder naturally preferred a soft stone, because it was easily worked and yielded him the largest profit.

One of the most important principles in the selection of stones for our climate is that "porous stones should not be used for the copings, parapets, window-sills, weather-bed of cornices, plinths, strings, or other parts of a building where water may lodge". Such rocks when used should be carefully tested for absorptive power; a granite which absorbs water to over one-half of 1 per cent. of its weight, is open to the suspicion of doubtful durability. Similar caution needs to be observed in the choice of freestones in our own climate.

Any sandstone weighing less than 130 pounds per cubic foot, absorbing more than 5 per cent. of its weight of water in twenty-four hours, and effervescing more than feebly with acid, is likely to be a second-class stone, as regards durability, where there is frost or much acid in the air.

The following statement by an English authority is of interest, not only because Caen stone has frequently been brought to New York in small quantities, and was once employed in construction of the fronts of the old building of the Nassau bank, corner of Nassau and Beekman streets, and of others, and is still used for interior work, but from its applicability to our native soft limestone-freestones:

Experience proves that Caen stone will not resist the dissolving power of water charged with carbonic acid gas; and as the rain-water of our large towns contains a considerable quantity of that gas, it is not expedient to employ this stone in any situation where water is likely to lodge or even to be taken up by capillary action, unless indeed the projecting parts be protected by metal. In upright walling above the plinths, and in the sheltered portions of cornices, it can be employed when judiciously selected; and in internal work, with safety and economy. The bedding of the stone should be observed.

Mr. G. Godwin, F. R. S., of London, England, states, in regard to this stone, that much of it is really good, but affords only small blocks. That which is brought into England—

cannot be depended on and ought not to be used in external work. With regard to Buckingham palace, where Caen stone was used, that was perhaps the most remarkable failure that ever was witnessed. He recollected seeing the new front of that palace about a year or a year and a half after it was finished (1847), and he found many parts in a state of perfect ruin. Large masses of stone were in the habit of falling from the cornices, to the great danger of the sentinels below, and the result was the necessity of knocking off vast portions of the decorations and making them good with cement, painting them several times, with a frequent necessity for repeating that costly process.

Again, in regard to Westminster abbey, an English writer (*b*) remarks:

Of the exterior I will say nothing. All its old features had perished by the end of the seventeenth century, when they were vilely renewed, and this base restoration is now in its turn decayed.

The abbey had been built about A. D. 1245, its foundations of ragstone from Maidstone, and the rest of the building, of several limestones (Gatton, Caen, etc., and the firestone from Reigate and Godstone). It was afterward repaired with Bath and Portland stones. The greater part of the exterior is now in an advanced stage of decay.

Again there are certain rules of selection, often of local peculiarity, which are yet to be worked out, which refer to the adaptation of a stone to durability in certain positions, exposures, or parts of a building. A few such rules may be suggested as indicated by the study of the forms of decay in this city.

1. No temptation of cheap cost or facility of carving should permit the use—almost universal here—of a soft freestone in the stoops, balustrades, etc., where exposed to sun, street-dust, and wear, unless protected at least by some artificial means.

2. The finest-grained varieties of brownstone, with imperfect lamination, may be introduced with advantage for the projections and those parts most liable to decay, even where coarse material is generally employed in the front.

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a *Jour. Soc. Arts, London*, 1860, Vol. 8, p. 249. *b* Gilbert Scott: *Mediæval Architecture*, Vol. I, p. 176.

3. The life of a brownstone is more apt to be prolonged in a shady but dry exposure, *e. g.*, on the south side of an east and west street, or the west side of a north and south avenue, the shady side of a stoop, etc., if care is taken to prevent the dripping of rain or thawing snow; if not, this position may render it the more liable to decay. Accordingly, a light-colored or more durable stone may be best selected for sun-exposed faces, where possible.

A porous absorbent stone should not be employed at or below the ground line, and the absorption of moisture from below should be prevented by the interposition of some impermeable material, as a damp-proof course. Attention to this rule would have prevented the decay which is shown at the base of most of our brownstone buildings of the earlier construction, usually to a height of one or two feet above the ground line, but sometimes two or three yards, as in the building on the southeast corner of Eighteenth street and Fourth avenue; almost the only decay visible in the excellent sandstone used in Trinity church, New York, is of this nature, extending about a yard above the ground. This experience has borne some fruit in our city, and the insertion of the close-grained compact graywacke or "blue-stone", or sometimes a granite, into the base of most of the recently-erected brownstone fronts, even as a narrow band at the earth line, probably tends to prevent, by its less porosity, the rise of water into the sandstone, and so to delay its disintegration.

SEASONING.—Vitruvius, the Roman architect, two thousand years ago, recommended that stone should be quarried in summer when driest; that it should be seasoned by being allowed to lie two years before being used, so as to allow the natural sap to evaporate, and that it should be tested as to its wasting. Little regard seems now to be paid to this condition, the stone being hurried from the quarry into the building.

It is a notable fact that in the erection of St. Paul's cathedral in London, England, Sir Christopher Wren required that the stone, after quarrying, should be exposed to season for three years on the sea-beach, before its introduction into the building. No such exhibition of carefulness can be witnessed on any sea-beaches in the vicinity of New York city.

POSITION.—It has already been stated that, in order to resist the effects of both pressure and weathering, a stone should be placed on its "natural bed". This usually indicates the plane of original deposition, but not always, contrary to the general statements of the text-books; (*a*) for the lamination may simply be the result of the last period of pressure, *e. g.*, slaty cleavage, in which Sorby and others have shown a rearrangement of the particles, scales, and flakes of the constituent minerals into a stable condition of parallelism. This is illustrated in the constitution of some varieties of our slates, schists, and "blue-stone", and the injury, caused by neglect of this consideration, in the rapid decay and ruin now in progress in the ashlar of our freestone fronts. The stone of one of our oldest buildings, Trinity church, New York, probably owes its excellent preservation in part to the careful attention which was given to the position of the blocks, while in others of comparatively recent erection, though constructed of small blocks of brownstone mostly laid "on bed", the surface of the stone has begun to exfoliate, but not so rapidly and deeply as in occasional blocks standing on edge; for example, many stones below the projecting string-courses in the west front of the church on southeast corner of Thirty-fifth street and Fifth avenue. In many of the most recent buildings the proper mode of construction is seen: *e. g.*, the blocks of gneiss in all churches of that material; the Indiana limestone in the house on corner of Fifty-seventh street and Fifth avenue; the Potsdam sandstone, usually in the new buildings at Columbia college; the brownstone in residences at Fifth avenue and Fifty-first street, and in the lately-erected wings to the Astor library, etc. On the other hand, no attention is paid to the matter in the common stone fronts throughout the city, whether brownstone or Nova Scotia stone. Many prominent buildings of recent erection show the same disregard of the principle, *e. g.*, the marble ashlar of the Union Dime Savings bank, in which a large number of the blocks stand on edge and are in many cases fissured; the Lenox library, in which about 40 per cent. of the ashlar consists, in the alternate receding courses, of blocks of the Lockport limestone set on edge; the Drexel building, on the southeast corner of Wall and Broad streets, in which all the white marble ashlar dressings and even the projecting quoins stand on edge, etc. Indeed, in this city the proper arrangement of building stones in this respect, where apparently observed, has really been rather a matter of the builders' convenience, due to the small size or square form of the stones employed, than of any scrupulous attention to the conditions of durability. Other phases of the principle involved in the position of stone in a building have been already sufficiently discussed.

FORM OF PROJECTIONS.—The following statement by an English authority possesses even greater claim to consideration, in the exigencies of our more severe climate:

> In this climate water will invariably accumulate upon an exposed projection, and from thence, by the natural laws of gravitation, will run downward upon the surface beneath. * * * The continued permeation by water must materially injure the durability of any structure. Upon brick and stone, especially in winter, is this effect noticeable, when the repeated alternate freezing and thawing rapidly affect the quality of materials, and by a disintegration of particles impair the strength of the entire mass. * * * All projections from a building exposed to the weather should be "throated", that is, a narrow groove should be cut, extending the entire length, upon their under side. The water gathering upon the upper part of the window-sill, or whatever the projection may chance to be, flows over the upper edge to the lower and to the under side of the sill, when, instead of following the surface by the attraction of cohesion and finally running down the wall, it is stopped by the groove, and from thence falls to the ground, being unable to further continue its progress upon the surface. The complete efficacy of this device and the ease with which it is adopted are most apparent, and, though it has long been in use, is rarely introduced among the specifications of an architect. (*b*)

a *Notes on Build. Construction*, Part III, p. 9. *b* *The Architect*, London, England, 1870.

The severity of our climate even requires the further care that the upper surface of projections should be so cut as to prevent the lodgment or long retention of deposits of either rain-water or snow. It is immediately above and below such deposits that the ashlar of our fronts is most rapidly corroded and exfoliated, an effect evidently due mainly to the repeated thawing and solution, freezing and disintegration, which are caused by the water, slush, and snow which rest, often for weeks, upon a window-sill, balcony, cornice, etc. Thus from the initial and inexcusable carelessness in the construction and form of the projections, and, later, the neglect of the house-owner, due to ignorance of the results involved, to remove the deposits of snow, etc., as fast as they accumulate on the projections, is derived a large part of the discoloration of the marble, Nova Scotia stone, or light-colored granite, and especially the exfoliation of the brownstone beneath the window-sills, balconies, etc., by the water alternately trickling down the front and freezing, by day and by night, for long periods.

The benefit of this plan is well illustrated on the east, south, and west sides of the city hall of New York city, the heavy projecting marble cornice of the string-course above the first story being deeply undercut, and affording a complete protection from the rain to the line of dentilated decoration immediately beneath it. Accordingly the latter displays no evidences of decay. On the other hand, the general need of this device is testified by a study of the course of the decay which attacks the stone fronts of our buildings. In almost all cases the first part of the ashlar to decay is that immediately beneath the windows. If the projecting stone sill is horizontal, or inclines slightly outward and downward, the rain-water falling upon it, and, still more, that derived from the thawing of the snow which lodges in winter upon the sill, flows over the front edge of the sill, over its under surface, and down the surface of the ashlar to the lintel of the window below, in a band as wide as the sill above, or sometimes farthest along a line beneath the middle of the sill, and so produces a triangular or rectangular patch of moisture on the stone, with the apex reaching partly or entirely to the lintel of the window below. If, however, the sill inclines inward toward the house, the water trickles from one or both ends of the sill in a narrow band down the ashlar. After a storm, when the house-front has become rapidly dried, partly from the wind, partly from the free drainage down the lamination-planes of the ashlar standing on edge, the stone sill remains water-soaked from the horizontal position of its laminæ, or from the thaw of the snow lodged upon it, and these triangular patches or the lateral streaks are kept moist, it may be, for days afterward. Throughout that portion of the ashlar, therefore, chemical action by day and the work of frost by night continue in progress alternately far longer than elsewhere upon the front. If the material is brick the surface is first discolored, the mortar removed from the joints, and at last the surface of the brick itself is eroded under the patches or streaks of moisture. Examples of this are seen in the brick fronts of the older streets.

If marble, the surface assumes a dirty yellowish color, the joints are widened, and the surface soon becomes roughened. Examples are seen in the marble fronts on the north side of Murray street, between Church street and West Broadway, etc.

If light-colored freestone, a blackish-gray, irregular discoloration begins, which may become very disagreeable to the eye, and a serious decay ensues. Examples are seen in fronts on the corner of Christopher street and Greenwich avenue, etc.

If brownstone, the discoloration hardly precedes the rapid disintegration, the surface peeling off in thin sheets over the triangular patches below the windows, or in long vertical streaks or bands on either side to the depth of 1, 2, or 3 centimeters, even while the general area of the front still retains, in sharp contrast, the smooth surface of its original dressing. Examples of this destruction are seen in its first stages all along the lower part of Fifth and Madison avenues below Forty-second street, and, still farther advanced, in the older streets.

If granite, discoloration has been often produced, but the use of this excellent material is too recent in our modern city to furnish the evidences, sure to follow, of deeper disintegration.

Again, the surface of the ashlar exhibits a similar decay just above the lines of projections, *e. g.*, of long business sign-boards, heavy string-courses, cornices, the lintels of doors and windows, etc., peeling off in the same way as the lowest courses of the front just above the ground line. This, too, seems to be chiefly due to the snow which lodges on these surfaces, and, in thawing, keeps moist the surface above. So, also, balconies bring speedy destruction to the stone surfaces beneath them, especially if their flooring permits the trickling of water down the front, and at the same time shelters it from the sun and wind. Thus, one may see in our streets, for several days after a snowfall, entire blocks of the finest residences with their fronts spotted with snow on all projections, constantly thawing and freezing, with corroding streams of water trickling their way down the front. In most cases these snow deposits on window-sills, lintels, etc., could be as readily swept from their lodgment by means of a broom, as they are always removed from the sidewalk. The neglect—which, if applied by our servants to the destruction of furniture within the same houses, would be denounced as slovenly carelessness—is simply due to ignorance.

It requires, therefore, but little observation of our buildings to recognize that, like the beak of the pelican tearing its own breast, the sills and similar projections are serving to eat away the material of the front lying below. A clear understanding of the nature and progress of the erosion, as above described, is first desirable; and this seems to indicate the advisability of adopting, for prevention, some simple device in regard to the window-sills, such as the choice of impervious material not easily water-soaked (perhaps blue-stone), cut in such form above as to prevent the easy lodgment of rain-water or snow, and throated with a groove underneath the projection to prevent the continuous trickling of water down the front. No such attention appears to be given to the character of the window-sills of most buildings by our architects, though the desired result has been obtained, where a properly throated string-course or cornice coincides with the sills of a line of windows (*e. g.*, in many churches, in a new building of Columbia college, on Forty-ninth street, and also in some churches recently erected), by dispensing with any projection beneath a window and replacing it by a long slope from a narrow, protected sill into the vertical plane of the front—*e. g.*, in the churches on northeast corner of Sixty-sixth street and Madison avenue, etc.

B. ARTIFICIAL MEANS OF PRESERVATION.

Many methods, mostly empirical, have been suggested for the artificial prevention of the decay of building stone, which may be here briefly considered, particularly those which have been resorted to in New York and the adjacent cities. The descriptions of the processes in detail are given in the text-books, (*a*) and it will be necessary to give in this report only the details of processes locally employed. The preparations recommended for this purpose are of two classes, organic and inorganic, according to the nature of the materials used.

1. ORGANIC PREPARATIONS.—All the preparations of this class, depending on the application of a coating of paint, etc., or on the injection of fatty matters, are in their very nature of a temporary character. They have been properly denounced as only costly palliatives, needing frequent repetition, and, therefore, exerting an influence toward the destruction of delicate carving. G. R. Burnell remarks on this subject: (*b*)

> The objection to oil paints consists in the fact that, in proportion as the oils which serve as their vehicles evaporate the particles of the stone they originally protected become again exposed, and even the absorbent powers of the stone itself contribute to this action. It, therefore, becomes necessary to repeat the painting frequently, and thus, in the end, the delicacy of any moldings or carving must be effaced. The unequal rates of expansion of the stone and of the oil paints in time of frost tend to increase the danger of irregular and unequal exposure above attributed to the evaporation of the oil.

Professor Ansted, F. R. S., observed on the same occasion:

> It was easy to see that if a stone could be coated in such a way that moisture could not get into it, and provided there was no moisture in the stone already, the thing was done. But the difficulty was to manage this, and it arose from the fact that no paint, no substance that contained organic matter, could, by any possibility, be long of any use. It might last for a time, but if it was capable of being acted upon by the atmosphere, and became oxidized, then after a time it failed; the surface peeled off and the moisture got in. The moment the moisture got into the stone the mischief began, and the work of destruction would go on as much as if the stone had never been covered at all. The difficulty was to find some material which would form a permanent coating upon the stone, preventing the entrance of atmospheric moisture, and doing so in such a manner that it was not liable to decay from the atmospheric influences to which the stone was exposed.

Coal-tar.—This has a special use in the protection of foundations of weak materials from moisture; the walls and masonry of tanks from acid vapors, etc. (*c*) New York city is fortunately provided with an abundance of excellent material for foundations in the underlying gneiss of the island.

Paint.—In New York I believe this has very rarely been employed for the protection of stone, and could have no lasting effect. By its use in repeated coats, however, the durability of the fronts of Caen stone of several buildings in the lower parts of the city (*e. g.*, the old building of the Nassau bank, the Tontine building, etc.), has been preserved for many years. At Washington a portion of the base of the stone front of the old Capitol, consisting of Potomac marble, was found to be crumbling from rapid decay, and the Secretary of the Interior reported in 1849 that "if left wholly unprotected from atmospheric influences for one-third of the time that marble structures are known to have stood, the noble structure would become a mound of sand". It was subsequently painted, as well as the marble of other public edifices, the President's house, etc. In London, paint has been employed to protect the Caen stone of Buckingham palace, erected in 1847, etc.; the Portland stone of many private and public buildings; the marble of monuments, *e. g.*, that in front of Saint Paul's, etc. A coat of paint is said to last hardly three years.

Oil.—This always discolors a light-colored stone, but only produces a darker shade on our brownstone. For this it has been applied to several buildings, *e. g.*, the first house on south side of Fifty-fourth street, west of Fifth avenue; a house in Sixtieth street, between Fourth and Madison avenues; Trinity church, Brooklyn, etc.

The following is the method employed in its application: The surface of the stone is first washed thoroughly clean, allowed to dry, then painted with one or several coats of boiled linseed oil, according to the taste of the owner, and finally with a weak solution of hartshorn in warm water to produce uniformity of tint. The oil has been found to sink about a quarter of an inch into the stone. Any new block afterward inserted into a front thus oiled, in undergoing repairs, will need to be oiled in the same way. A front treated by this process may be recognized by its darker color and by the fact that during a rain the water freely runs down the surface, which afterward dries more rapidly than an ordinary front. The experience of several builders and house-owners testifies that such a coating of oil will last four and even five years, very rarely longer, then becomes grayish, partially disappears and requires renewal, and so on repeatedly from period to period. Whenever such a front is taken down, it is found also that the greasy coating interferes with the free dressing of the block of stone.

Paraffine dissolved in coal-tar naphtha ($1\frac{1}{2}$ pounds to the gallon) and applied warm. This also discolors a light stone, and, although more lasting than oil, the protecting coats are gradually detached from the stone and

a *Notes on Build. Construction*, Part III, etc. *b* *Jour. Soc. Arts, London*, 1860, Vol. 8, p. 245. *c* *The Manufacturer and Builder*, 1870, I, p. 78.

require renewal as frequently as those of paint. An apparently better method, which has been employed in our western cities, consists in brushing over the surface of the stone- or brick-work with melted paraffine, and then deepening its penetration by heating the surface by means of a broad charcoal stove or of a flame. By this the outer pores are thoroughly filled, with little or no discoloration; but the absence of injury to sharp edges, through the direct application of heat, and the permanence of the protection, are yet to be established.

Soap and alum solutions (Sylvester's process), consisting of three-quarters of a pound of mottled or soft soap in a gallon of boiling water, and a half pound of alum in 4 gallons of water. In England "this has been repeatedly tried and answers well in exposed situations, but requires a fresh application about every three or four years".

Beeswax in coal-tar naphtha, or, better, to preserve the color of the stone, white wax in double-distilled camphine.

Rosin in turpentine, oil, wax, tallow, or other fatty substance, used as a boiling solution into which the stone is immersed and impregnated to the depth ordinarily of one inch after two hours. Also a solution of rosin in spirits of wine or naphtha, mixed with a solution of gutta-percha in naphtha. A common receipt consists of rosin, tallow, and oil, consisting of 1½ pounds common rosin, 1 pound Russian tallow, and 1 quart linseed oil; applied hot. By this the stone becomes water-proof, the damp cannot enter, and vegetable substances are prevented from growing upon it.

However, all such wax and oil varnishes are costly, liable to rapid oxidation, and sometimes impair in a high degree the color and the natural characteristics of the stone. In New York city only oil and paint have been used for the purpose, to my knowledge, and are objectionable, not only on account of their transient effect, but because a surface, once so prepared, is rendered ever after incapable of absorbing preparations of the next class (inorganic), from which alone can be expected permanent protection of the durability of a stone.

2. INORGANIC PREPARATIONS.—*Water-glass, potassium or sodium silicate* (Kuhlmann's process), applicable only to the preservation of soft limestones and marble, or stones in which calcium carbonate predominates. The surfaces are previously colored to avoid discoloration. The silicate of alkali used should not be the ordinary water-glass with an excess of alkali, but one with the greatest possible amount of silica.(*a*) This was applied to the new houses of parliament, London, England, but the stone was so bad, or the water-glass so alkaline, that the result was not as satisfactory as was expected; also to the Louvre and cathedral of Notre Dame in Paris, France, Versailles, Fontainebleau, the city hall in Lyons, the cathedral at Chartres, etc.

St. Charles church in Vienna, Austria, was fast going to destruction, but the decay has been arrested by means of this process. Potassium silicate was used, though more costly, because less likely to effloresce than the sodium salt; the two coats applied were perfectly transparent and left the color and the natural qualities of the stone unchanged. (*b*)

Water-glass and chloride of calcium or of barium (Ransome's indurating solutions). The following directions are given for this process: Render the surface of the stone clean and dry; dilute the potassium or sodium silicate in from 1 pint to 3 pints of soft water, just thin enough to be absorbed freely by the particular stone. Apply with a whitewash brush, say a dozen times, leaving no excess on the face, till it ceases to penetrate, and is about to remain glistening on the surface; allow it to dry perfectly, a clear day or so; then apply freely the solution of calcium chloride, brushing on lightly without froth. (*c*)

Szerelmey's stone liquid. Water-glass, combined with a temporary wash of some bituminous substance.

Petrifying liquid of Silicate Paint Company. *Barium solution*, followed by ferro-silicic acid, or barium solution, followed by calcium superphosphate; soluble *oxalate of aluminium*, applied to limestones. The last three processes produce no efflorescence upon the stone.

Wash of copper salts, as proposed and used by Dr. Robert, in Paris, to arrest the formation and growth of vegetation on the surface of stone. The results already reported imply a considerable aid in the preservation of building material, and may yet be found serviceable in New York to prevent the growth of *confervæ*, etc., which find a favorite habitat as a green film upon the shaded surfaces of Nova Scotia stone, and, as especially observed in Central park, seem to exert a corrosive action upon them.

In New York, various preservative preparations have been used within the last ten or fifteen years, styled "silica petrifying liquid", "duresco," etc., especially on the brick-work, but partly on the brownstone of many buildings (*e. g.*, the brownstone of the *Evening Post* building, four years ago; the brick factory in Twenty-eighth street, between Sixth and Seventh avenues; the brick-work in the rear of the Florence flats, Eighteenth street and Fourth avenue; the brownstone houses on southwest corner of Thirty-ninth street and Fifth avenue; the brick-work of the gables and top bed of all platforms in the balconies of the Union League club in Fifth avenue, etc.). In most cases these preparations, so far as tried, have resulted in complete failure, not arresting the exfoliation.

To my knowledge, no investigation worthy of the name has yet been undertaken in this city for the protection of its stone-work, though there is every promise that a proper and low-priced preservative might be discovered, possibly even in the refuse of some of our chemical factories. If not for the ashlar of the fronts, at least for the

a For mode of preparation see *The Manufacturer and Builder*, 1871, III, 206: "How to prepare soluble glass."

b *Manufacturer and Builder*, 1869, I, 82

c *The Am. Arch. and Builder*, 1877, II, 21, 38.

hewn stones employed for window-sills, string-courses, cornices, and moldings, it would seem false economy to use any porous stone, without every condition of protection to be found, in the form of its cutting and in the application of a suitable artificial preservative.

It will doubtless be found that only those stones, which possess a porous texture and strong absorptive power for liquids, will be found particularly available for protection by artificial preservatives. In the spongy brown and light olive freestones, a marble full of minute crevices, and a cellular fossiliferous limestone, a petrifying liquid may permeate to some depth, close up the pores by its deposits, and incase the stone in solid armor; while upon a more compact rock, such as a granite or solid limestone, it can only deposit a shelly crust or enamel, which time may soon peel off.

In this connection, therefore, three suggestions may be offered: 1st, that householders invoke the magic use of the broom on the fronts of their residences as carefully as upon the sidewalks; 2d, that house-builders insist upon the undercutting of all projections, and the exclusion of brackets or other supports to sills and cornices, which only lead to the oozing of water and a line of corrosion down the ashlar; 3d, that house-repairers recut the projections in this way, whenever possible, and entirely avoid the use of paint, oil, or other organic preservatives.

If a rough estimate be desired, founded merely on these observations, of the comparative durability of the common varieties of building stone used in New York city and vicinity, there may be found some truth in the following approximate figures for the "life" of each stone, signifying by that term, without regard to discoloration or other objectionable qualities, merely the period after which the incipient decay of the variety becomes sufficiently offensive to the eye to demand repair or renewal:

	Life in years.
Coarse brownstone	5–15
Laminated fine brownstone	20–50
Compact fine brownstone	100–200
Blue-stone	Untried, probably centuries.
Nova Scotia stone	Untried, perhaps 50–200
Ohio sandstone (best siliceous variety)	Perhaps from one to many centuries.
Limestone, coarse fossiliferous	20–40
Limestone, fine oolitic (French)	30–40
Limestone, fine oolitic (American)	Untried here.
Marble (dolomite) coarse	40
Marble (dolomite) fine	60–80
Marble, fine	50–200
Granite	75–200
Gneiss	50 years to many centuries.

Within a very few years past it has become frequent to introduce rude varieties of rusticated work into the masonry of buildings in this city, or to leave the stone rough and undressed in huge blocks, especially in the basement or lowest stories, where it is under close and continuous inspection, and the results of its decay will be disguised by its original rough surface. Although there are certain large buildings in which such a massive treatment of stone may be appropriate, its common use, with stones of known feebleness or lack of durability, is a disingenuous evasion of responsibility and a mere confession of ignorance, want of enterprise, and despair, in regard to the proper selection of building material and in regard to its protection.

Finally, it may be pointed out that many of the best building stones of the country have never yet been brought into this city: *e. g.*, siliceous limestones of the highest promise of durability, allied to that employed in Salisbury cathedral; refractory sandstones, like some of those of Ohio and other western states, particularly fitted for introduction into business buildings in the "dry-goods district", storage houses, etc., where a fire-proof stone is needed; and highly siliceous varieties of Lower Silurian sandstones, such as occur near lake Champlain, quartzitic and hard to work, like the Craigleith stone of Edinburgh, but possessing the valuable qualities of that fine stone in resisting discoloration, notwithstanding its light color, and in remarkable resistance to disintegration.

As it is, we have many and need many varieties of stone for our various objects, but do not know how to use them. It is pitiable to see our new buildings erected in soft and often untried varieties of stone, covered with delicate carvings of foliage and flower-garlands, which are almost certain to be nipped off by the frost before the second generation of the owner shall enter the house. It is now time for one who loves stone to express his indignation at the careless and wasteful way in which a good material is being misused.

In conclusion, it is a point worthy of attention that there is at present a strong tendency among many owners of property, and therefore many builders and architects in New York, to entirely reject or greatly limit the use of stone in construction, both in the commercial district and in that which includes the better class of residences.

In the commercial district granite was for some time a favorite material, and constitutes many of our most important buildings. Later it was largely supplanted by the white marbles brought from numberless quarries in Westchester county, western Massachusetts, and Vermont; but of late another change of taste and judgment has occurred, and it has been observed:

> The architects of the present generation found commercial New York an imitation of marble, either in cast-iron or in an actual veneer of white limestone. They are likely to leave it brick.

This city, and, to a large extent, Brooklyn, have passed the period in which frame buildings were permitted, though they never were as abundant as in the newer cities and towns of the west, on account of the large supply of brick-clays along the Hudson river, and the easy importation of bricks from Europe and from points along our own coast. In the reports of the fire-underwriters, the stone is disregarded as a mere veneer, and all such buildings are properly classified as brick.

Less than 1 per cent. of our building material consists of stone, so that New York is now practically a city of brick. Examples of the preference now largely given to this material are found in many conspicuous structures which have recently risen in this city and Brooklyn: *e. g.*, the storage buildings at Forty-second street and Lexington avenue; the Produce Exchange building in lower Broadway; that of the Long Island Historical Society in Brooklyn, etc.

The definite character and use of many of the most important avenues and entire districts are yet unsettled; and there are abundant indications of cheap display, in fragile veneer and constructions of a temporary character, which are rendering this a period of shams. There are evidences, however, of the gradual recognition of the practical business advantages, in the way of credit and continuous patronage, which are derived from durable massive buildings, with solid and imposing façades, with which the business and names of firms may yet be associated for centuries. The general acceptation of this idea will form the last period—that of stability—in the history of our great metropolis, and then there will be a proper and intelligent use and increased demand for the several varieties of stone.

The present preference for brick is mainly due to the failure of granites and marbles to resist fire in the furious conflagrations in the tinder-boxes at Chicago and Boston—although brick walls as well become warped and useless in the re-erection of the buildings—and to a conclusion which appears to me hasty and uncalled for, from the unfavorable results of the experimental and unnatural trials, in fiery furnaces, of series of our building stones, by several investigators. Such a conclusion seems to be unwise and unfair, so long as our present habit of internal construction is aptly represented by the following description:

> Our buildings are, in truth, ingenious combinations of flues, greater or smaller, mostly of combustible substance, and commonly of thin material, set side by side across our floors and up our walls, opening out here and there into hollow spaces walled with wood, and out of our reach. Every fire that occurs gives us new warning that our way of building is unsafe. All our common methods have been developed in the effort to attain one class of qualities—lightness, quickness, and ease of construction, and economy, or rather cheapness. As usually happens to people whose aims are one-sided, we have got into trouble. Our buildings do not last; often they will not bear the use we put them to; they burn like straw. Other people have found out how to build better than we, but we like our own way, and we will learn nothing from them. We box our floors with thin plank set edgewise, our partitions with smaller pieces of the same stuff; we fur our walls with strips of the same. Then we case all in with thinner boards and friable plaster on still thinner lath. The building is a series of communicating flues partially protected outside, but wholly exposed within, through which fire and vermin may play at will, and through which we cannot trace them till they have done their mischief. All this is convenient and cheap, for it is quickly put up and takes little material. If we use iron, as we must, we make it hollow also for strength's sake. This would do no harm if the hollows were no larger than they need be, and were properly closed in; but we build great boxes to simulate masses of stone, and we expose them to the fires of blazing wood which we know will destroy them. At the persuasion of underwriters we put up cornices of galvanized iron, which will not themselves burn, but which are thin shells turned upon wood, and will at once convey the fire behind them. (*a*)

Add to all this our hatchways and elevator-shafts, by which a fire, starting in the basement, is conveyed at once to the attic, the beams of the wooden flooring often resting upon girders in the center of the building, as it were, a very house of cards—these girders, too, supported merely on slender stone piers in the basement, and on light iron pillars in the upper stories, and every floor filled with a mass of combustibles, especially in the "dry-goods district"; and we find an accumulation of materials in false and improper conditions, whose combustion will overcome the most refractory walls, and which should never be permitted to endanger human life and property in a so-called metropolitan city. On inquiry, I find among insurance men a unanimous conviction, decidedly and strongly expressed, that there is not in the city of New York a single absolutely fire-proof building—not one whose walls may not crumble before a storm of fire from without, or in which either flooring or partitions, or both, will not probably yield to the internal conflagration of their ordinary contents. A few edifices may approach the conditions required, but even in one of these a recent fire on the seventh floor, fed merely by office furniture, shriveled up the flimsy so-called "fire-proof" partitions and gutted the entire floor. The very material, perforated brick, which was used in these partitions, is still being hurried into new "fire-proof" buildings, now in process of construction in Fiftieth street and elsewhere. Nevertheless, it is generally admitted that much progress and great improvement have been made, during the last few years, both in the choice and arrangement of building materials for the protection of our buildings from fire; with an enlightened public opinion, much more may be expected. We have, fortunately, at our very doors, vast tracts of fire-proof materials—the belt of brick-clays along the Hudson river, and the still more extensive band of clays stretching across New Jersey, excellently adapted for all varieties of bricks, terra-cotta, and tiles, to say nothing of the resources of our commerce in the importation of similar materials from the whole Atlantic coast—which we ought to and must use for interior construction as a matter of the wisest economy, and, in association with which, our building stones, in all their variety and enormous supply, will find their proper place. When, at least in the business districts of the city, the interiors of the buildings are generally supplied with a minimum of wood, subdivided with tile, slate, or concrete flooring and doors, and sufficient partitions of brick or terra-cotta,

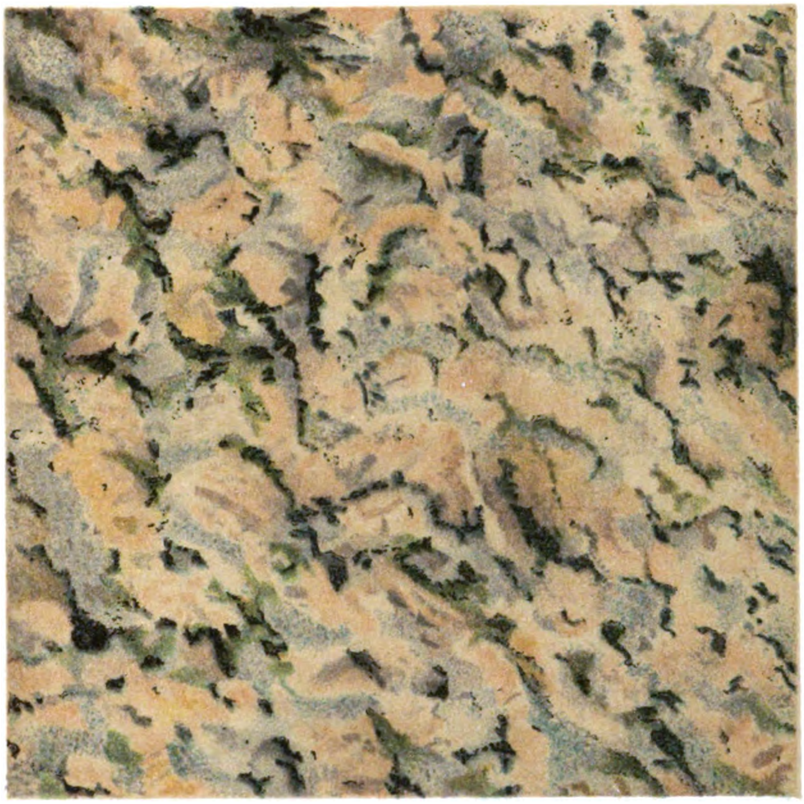
a The *Arch. and Build. News*, 1879, V, 49.

and roofed with tile, slate, or concrete upon fire-proof backing or supports, the nature of the stone used for the exterior will matter little, so far as concerns protection from fire, since it will not be exposed then, as now, to the unnatural and unnecessary furnace-test of furious flames from neighboring buildings.

The other objection to the use of stone, and one which has been specially prompted by the decay of the brownstone ashlar employed extensively in our buildings for private residence, is founded upon its lack of durability and speedy dilapidation or discoloration. The hasty statements of despairing architects, in denunciation of the brownstone, are sufficiently answered by reference to the texture of the still softer oolite, which mediæval architects were content to employ, and whose fragility seems to have been at last counteracted by modern devices. When proper investigations shall have been made, it is probable that the very porosity of the stone, which now renders it particularly sensitive to atmospheric attack, may best avail for the absorption of some cheap and durable mineral preservative, and that the present use of such stone in its raw, crude, and unseasoned state will be hereafter considered merely an evidence of the unintelligent and wasteful way in which we now work up our materials. Surely, since our city is placed in a region occupied on every side by inexhaustible supplies of sedimentary and crystalline rocks, remarkably well fitted for building construction, their surfaces scraped nearly bare by ice-action during the great glacial period, and thus most favorably exposed for economical exploitation, and the whole region is crossed by a radial network of routes of transportation by water and rail, at the least cost, centering in this city, the natural materials for building thus offered to us should not be hastily neglected or rejected, before their nature has been thoroughly understood.

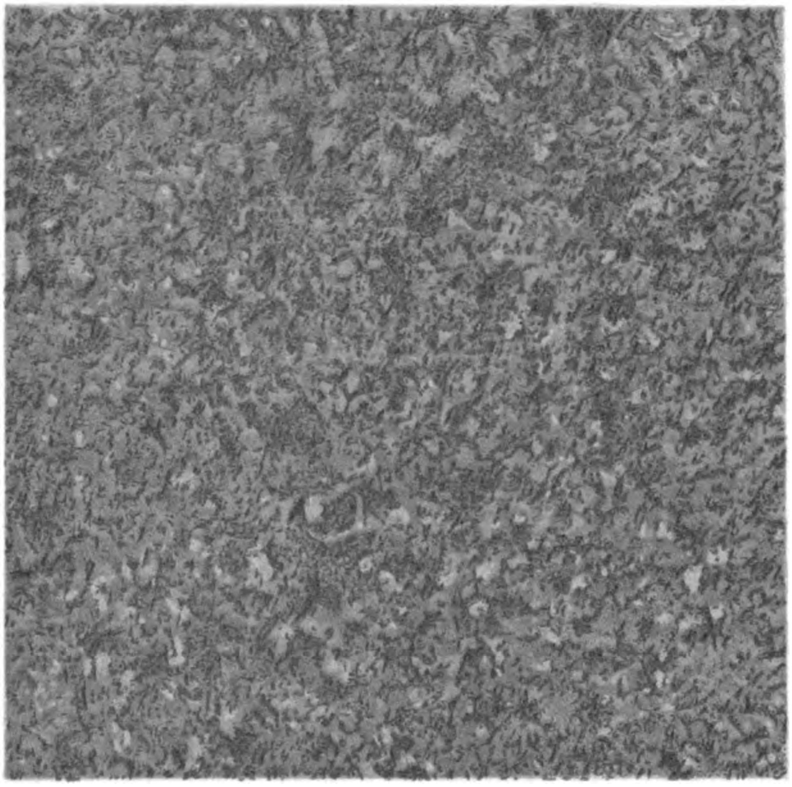
BIOTITE GRANITE

RED BEACH, MAINE



BIOTITE GRANITE WITH EPIDOTE

LEBANON, GRAFTON CO., N. H.



[illegible] GRANITE

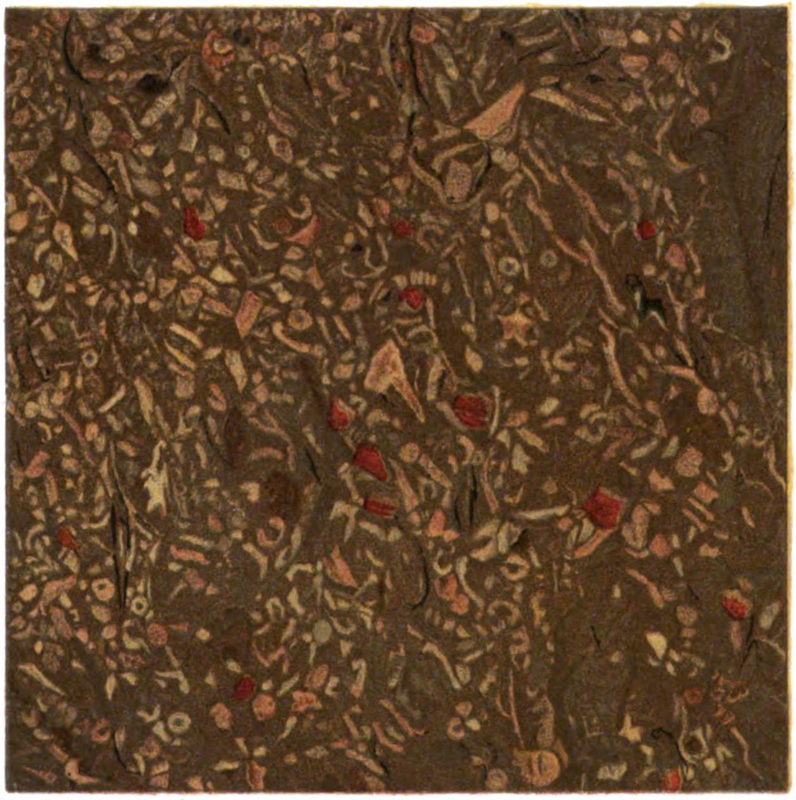
[illegible]

MARBLE

MALLETT'S BAY, VT.

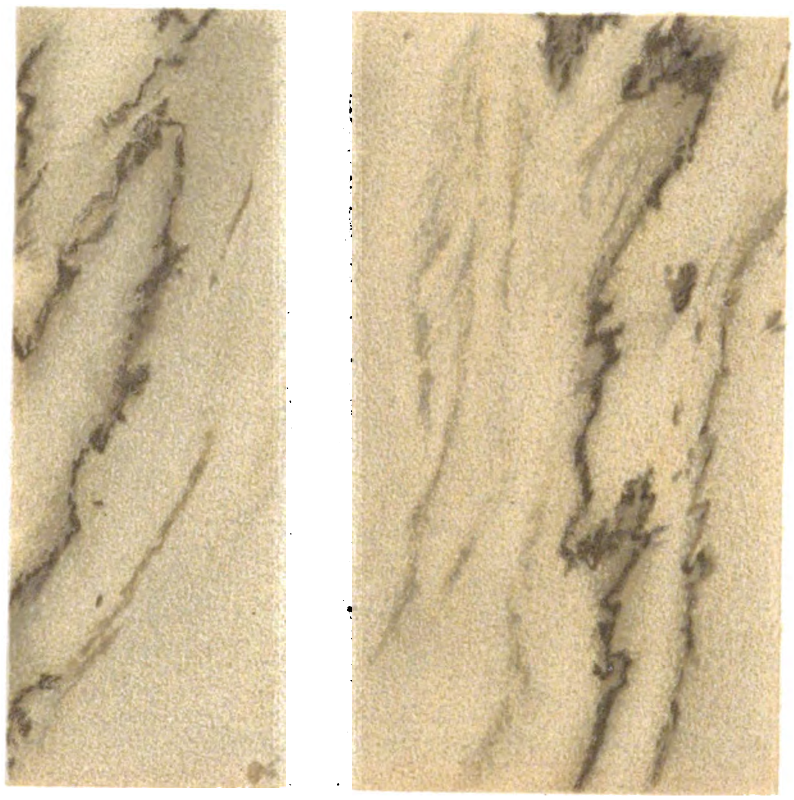
MARBLE

MALLETT'S BAY, VT.



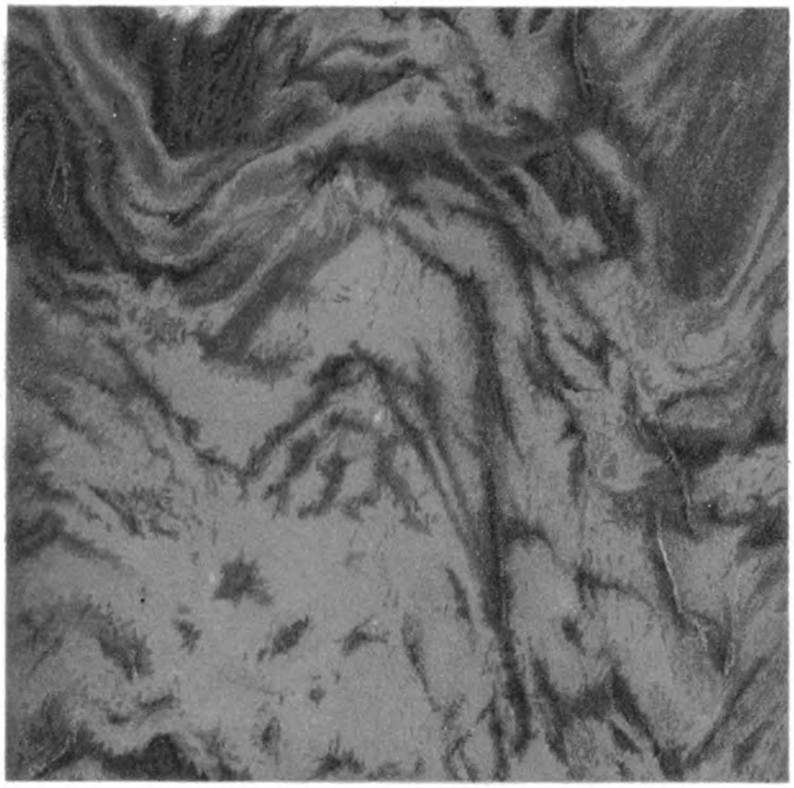
"LEPANTO" MARBLE

ISLE LA MOTTE, GRAND ISLE CO. VT.



MARBLE

SUTHERLAND FALLS, VT.

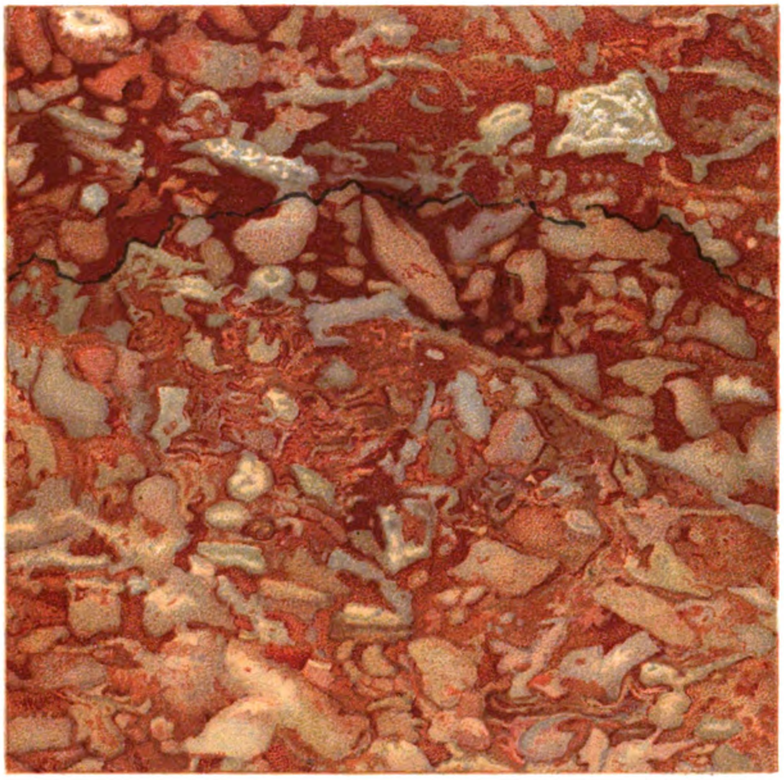


MARBLE

RUTLAND, VT.

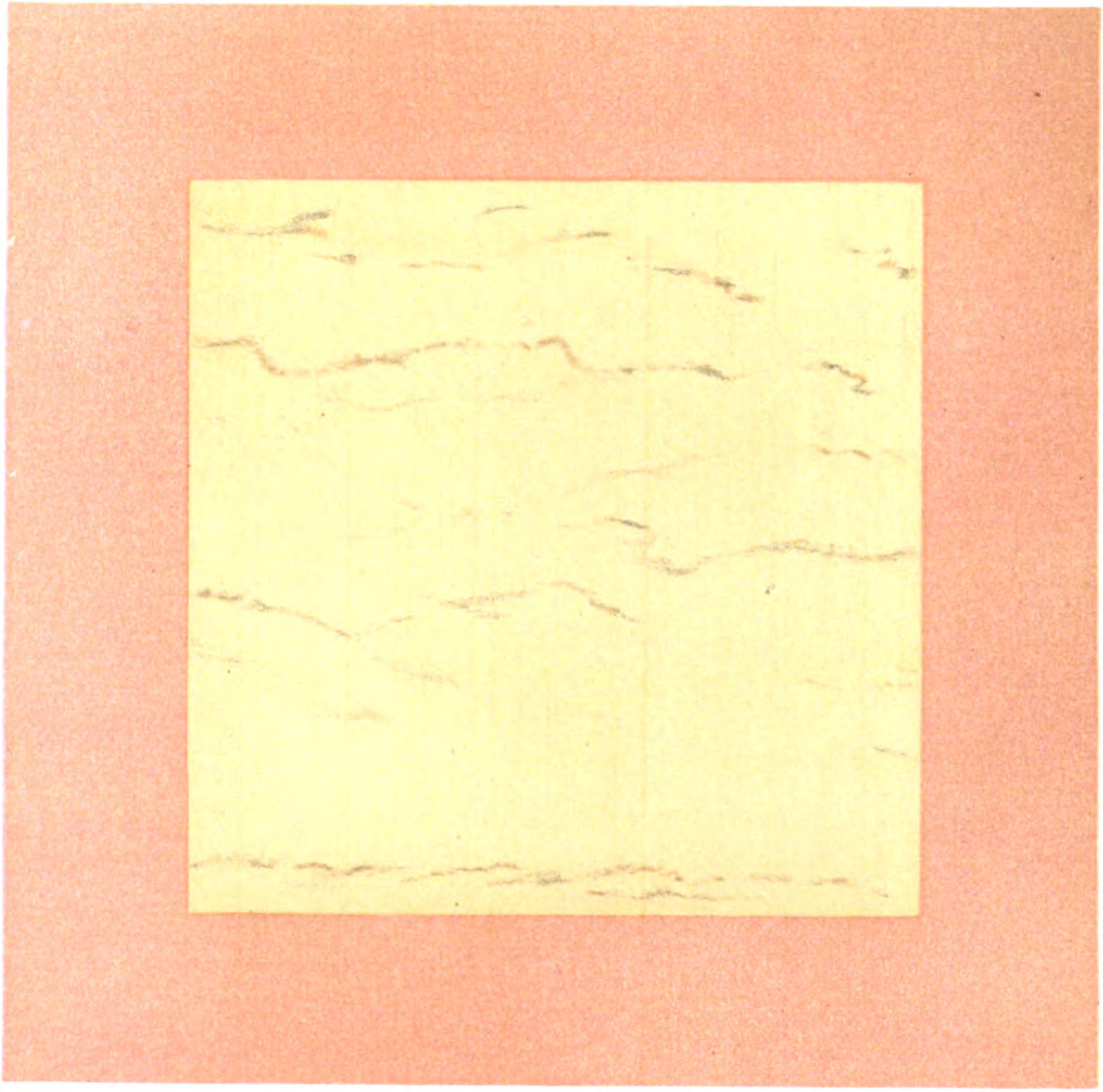
MARBLE

SWANTON, VT.

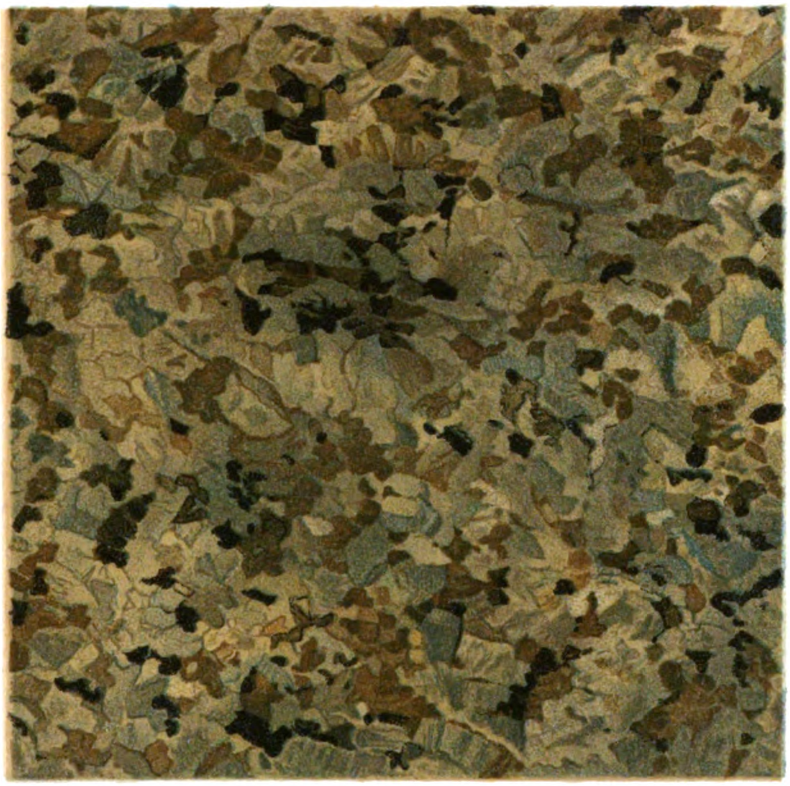


MARBLE

MALLETT'S BAY, VT.



MARBLE

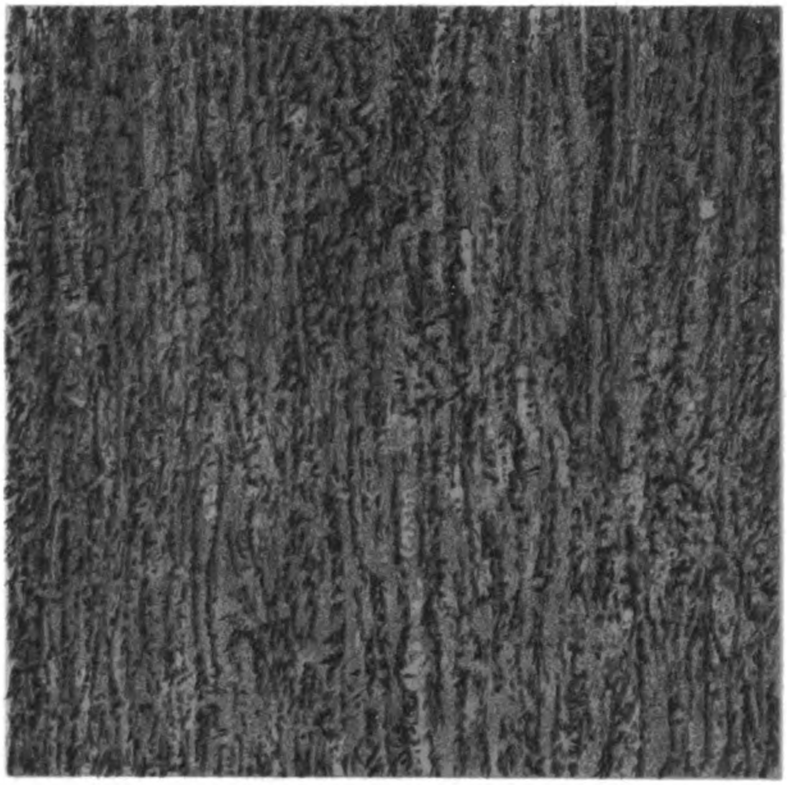


HORNBLENDE GRANITE

PEABODY, MASS.

BIOTITE GRANITE

WESTERLY, R. I.

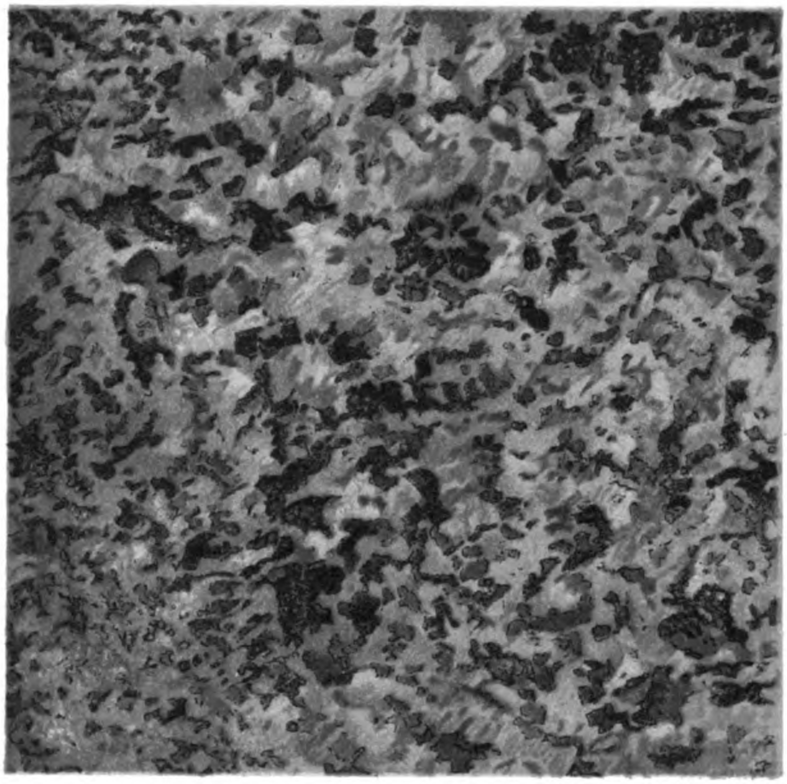


HORNBLENDE BIOTITE GNEISS

MIDDLETOWN, CONN.

HORNBLENDE GRANITE

GRINDSTONE ISLAND, JEFFERSON CO. N.Y.



MARBLE

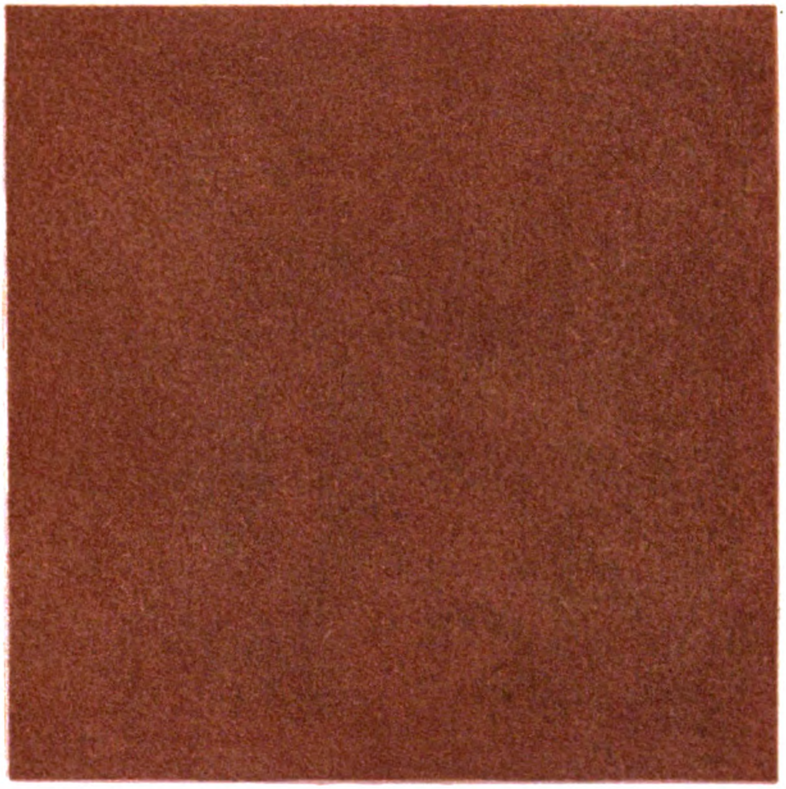
PORT HENRY, ESSEX CO., N.Y.

SANDSTONE

HUMMELSTOWN, DAUPHIN CO., PA.

MARBLE

KING OF PRUSSIA, MONTGOMERY CO. PA



TRIASSIC SANDSTONE

SENECA CREEK, MD.

LIMESTONE BRECCIA.

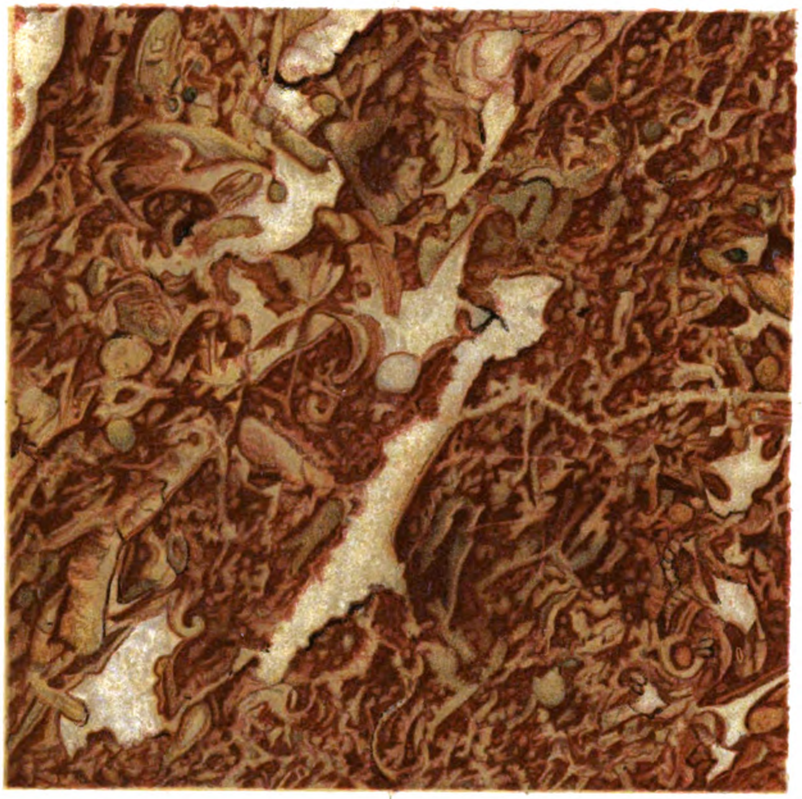
POINT OF ROCKS, MD

SERPENTINE

HARDFORD CO. MD

BIOTITE GRANITE

BENNETT CO., TEXAS.

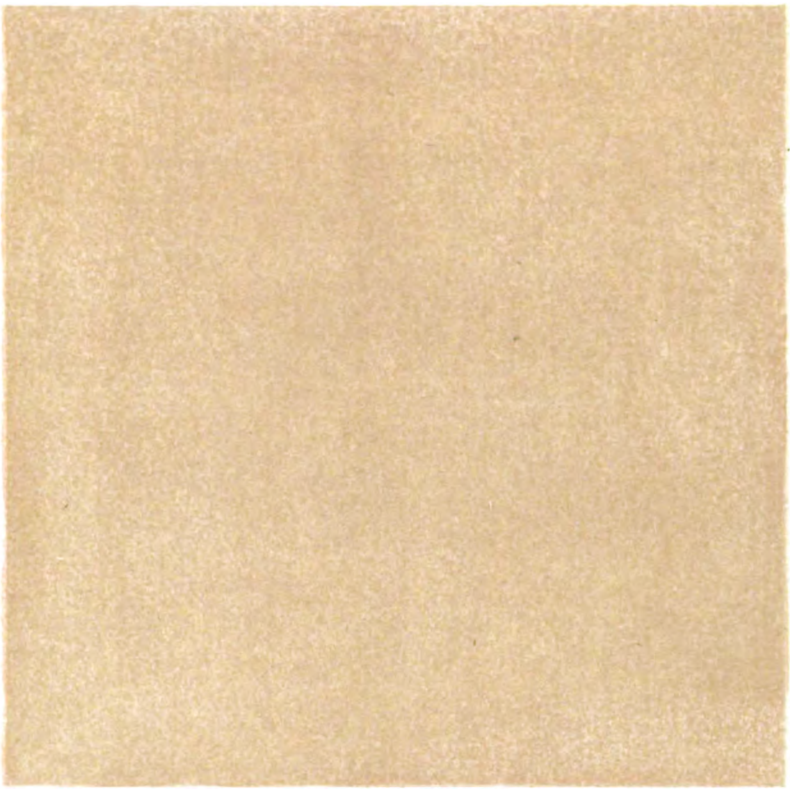


MARBLE

ROGERSVILLE, HAWKINS CO., TENN.

SANDSTONE.

[illegible]

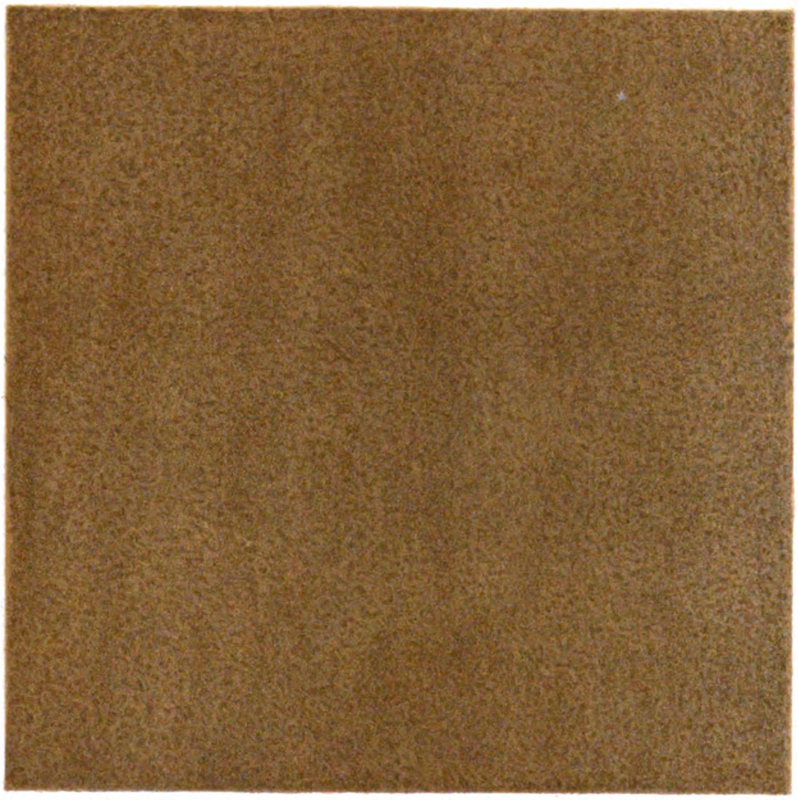


WAVERLY SANDSTONE

SUNBURY, DELAWARE CO. OHIO

LIMESTONE

MONTGOMERY CO. OHIO

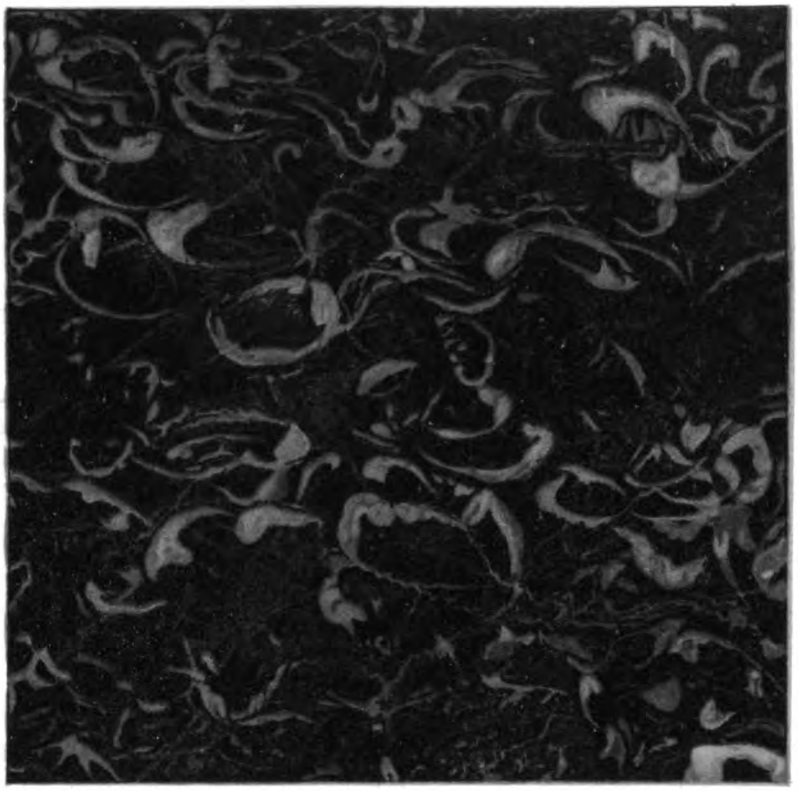


LIMESTONE

BEDFORD, LAWRENCE CO., IND.

BIOTITE GRANITE

IRON TOWNSHIP, IRON CO., MO.

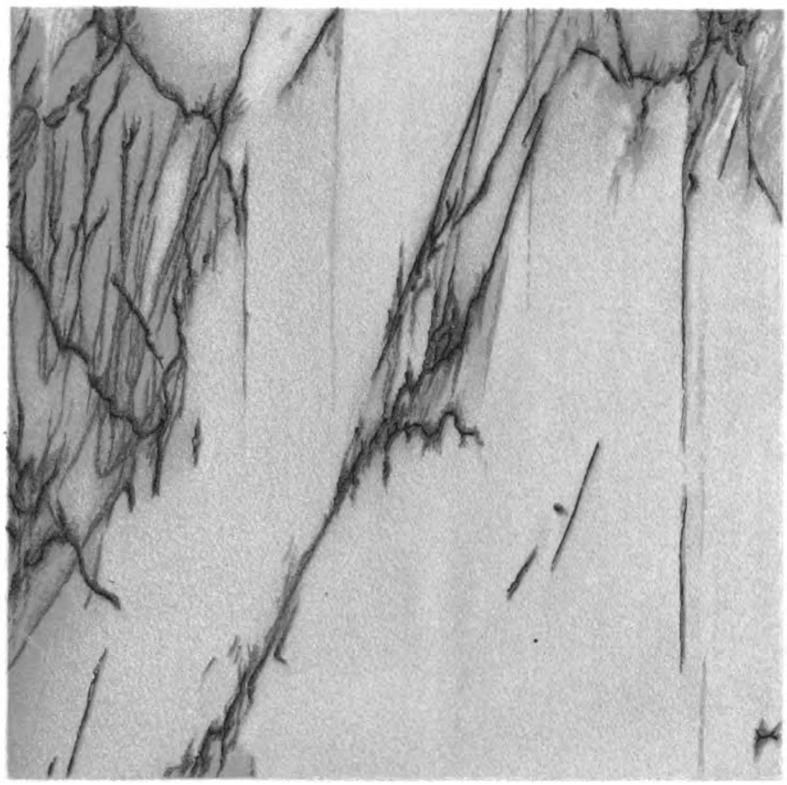


MARBLE

PAYSON, UTAH

STALAGMITE MARBLE

SOLANO CO. CAL.



MARBLE

INDIAN DIGGINGS, ELDORADO CO. CAL.